

October 28, 1999
Fermilab

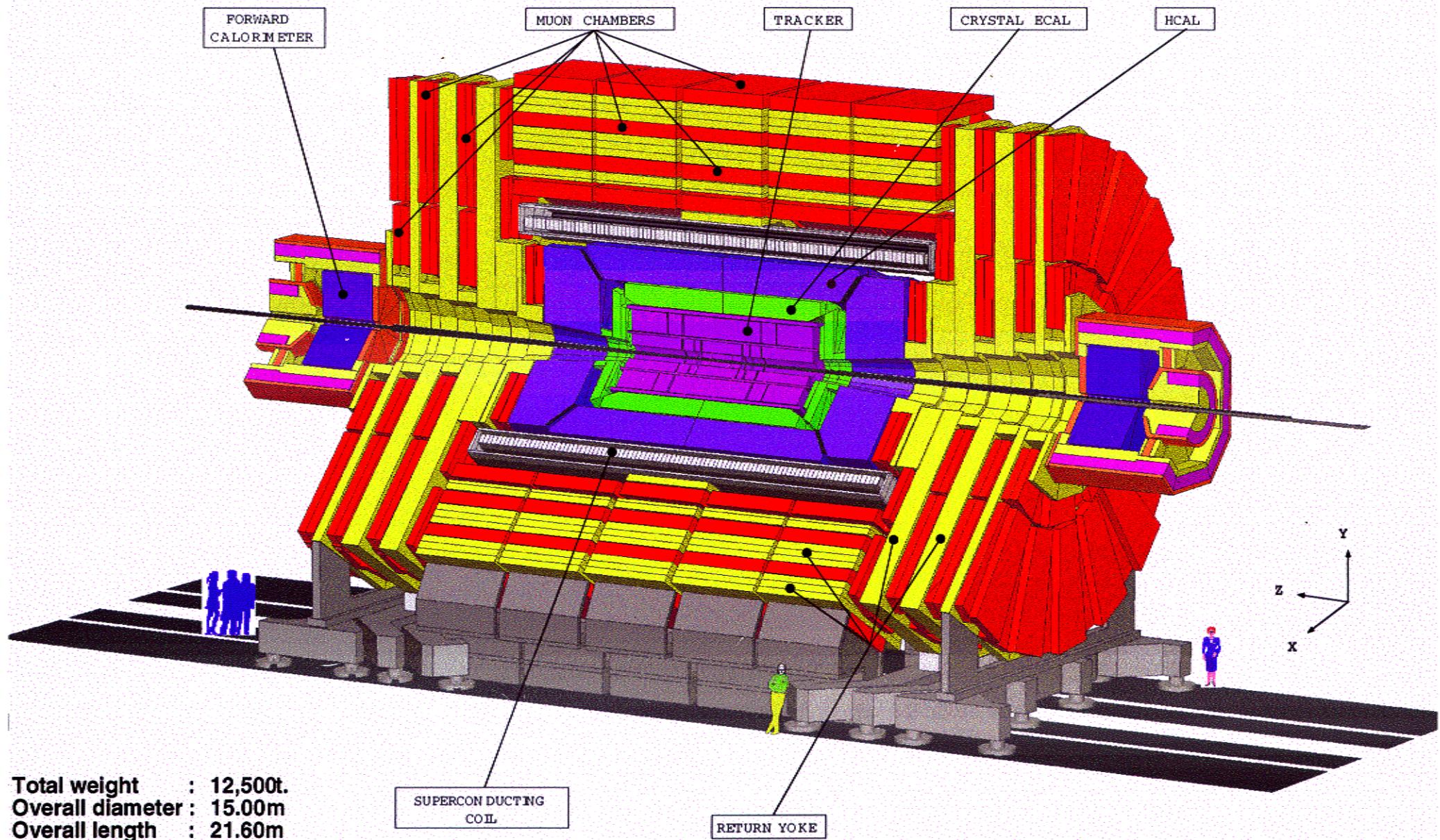
Prospects for Higgs (SM and MSSM) searches at LHC

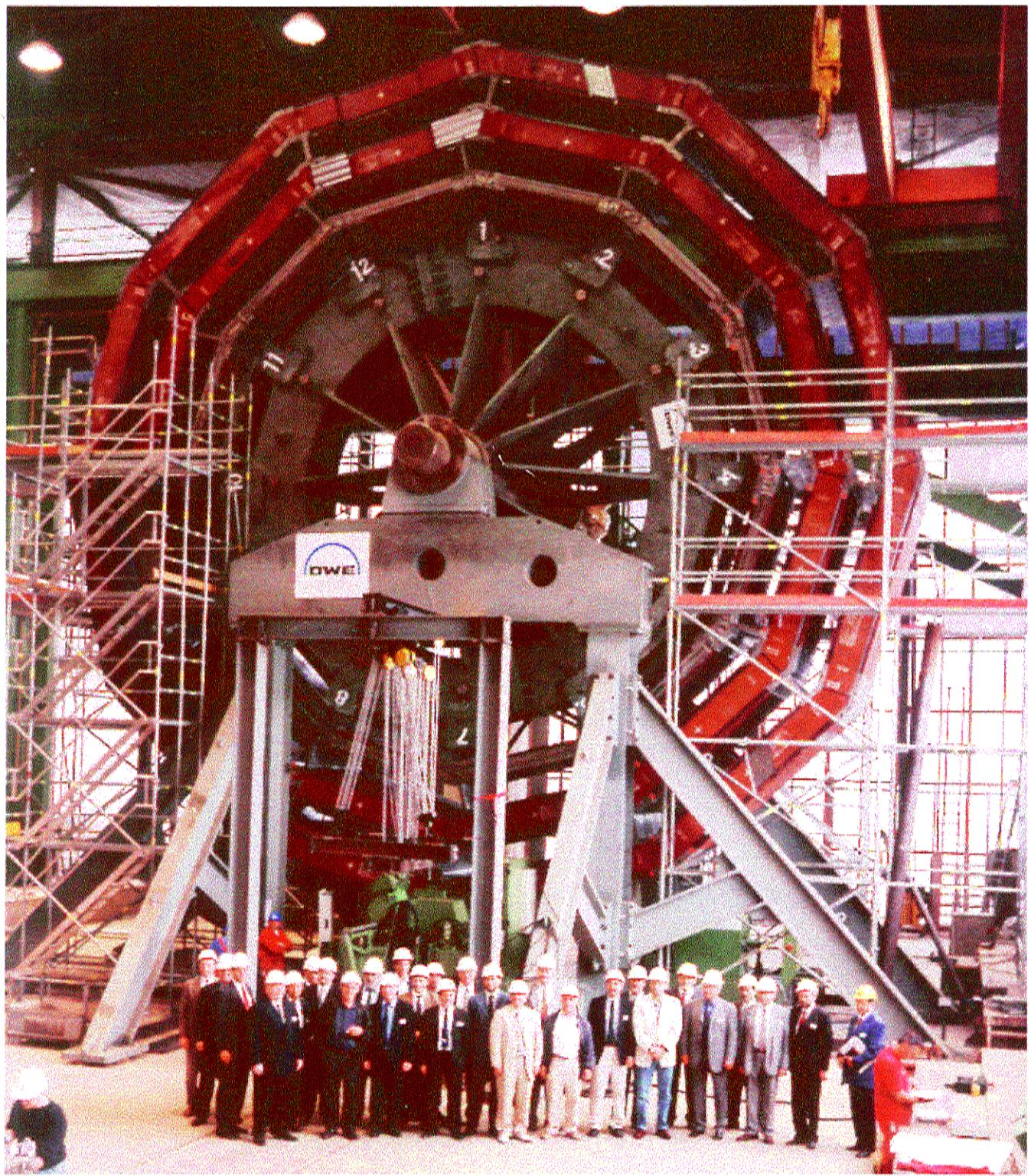
D. Denegri, CE Saclay

- SM Higgs,
channels, mass reach, precision
- SUSY Higgs searches,
channels, parameter space coverage

CMS

A Compact Solenoidal Detector for LHC

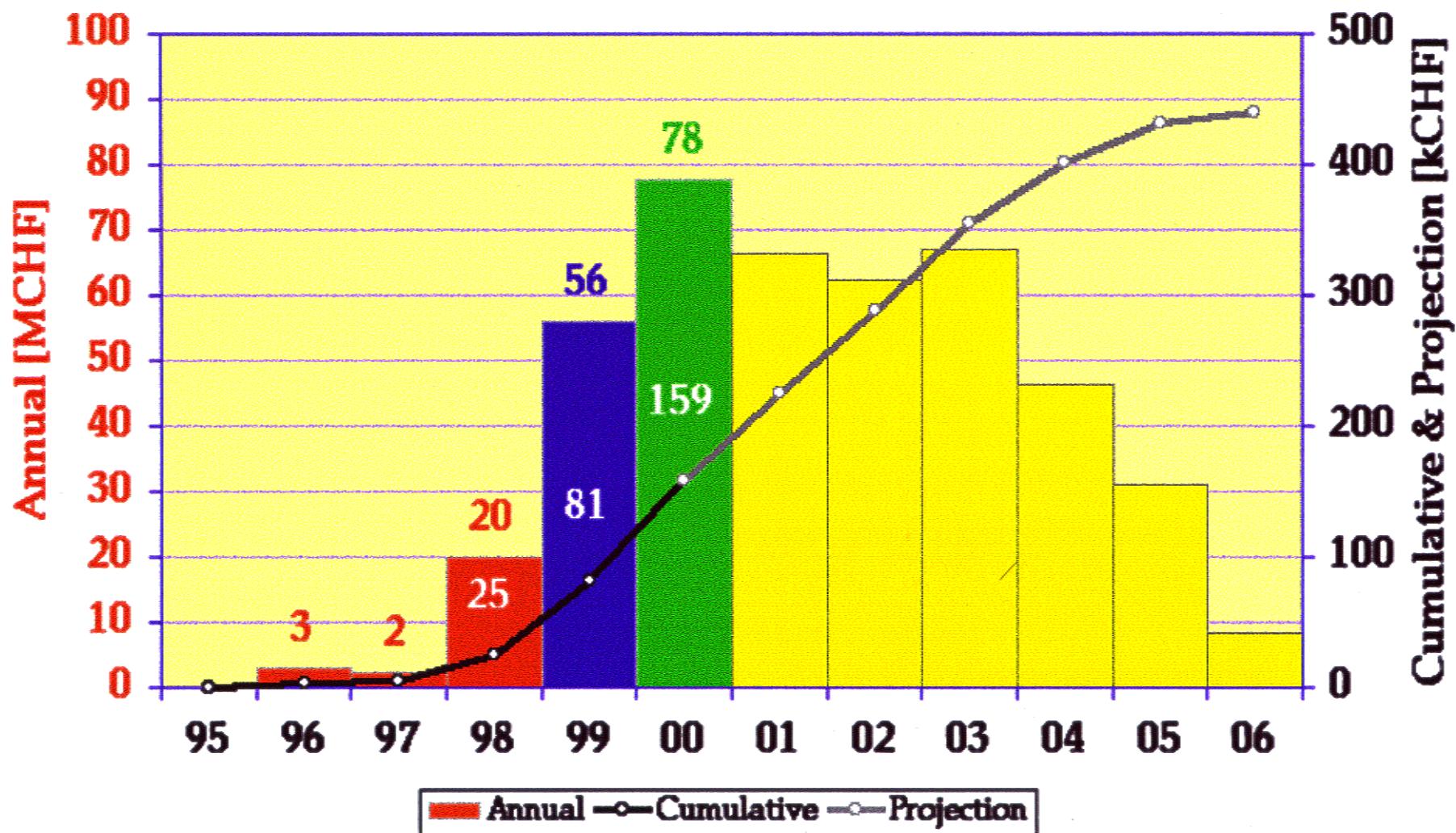


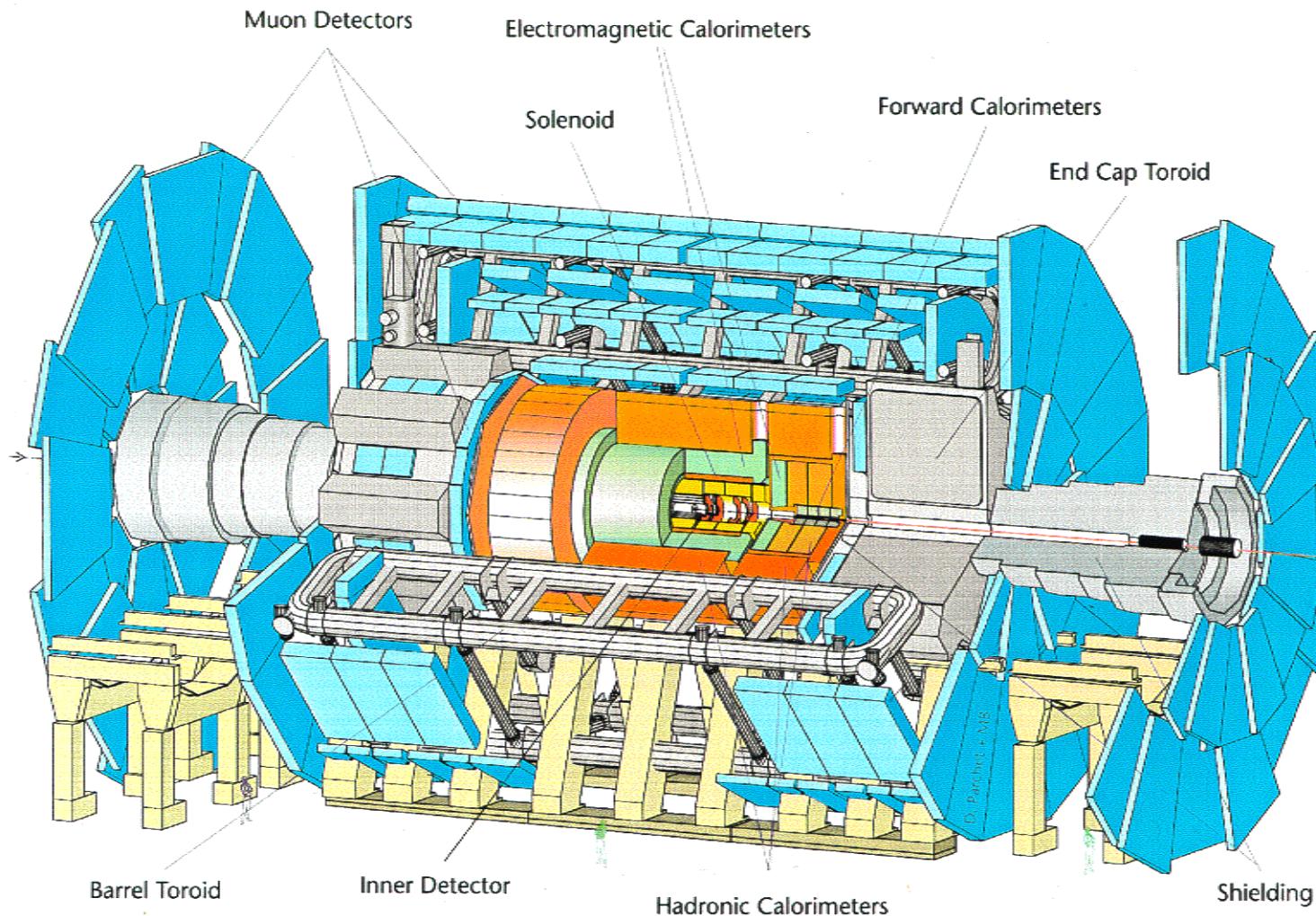


HCAL Beam Test Layout

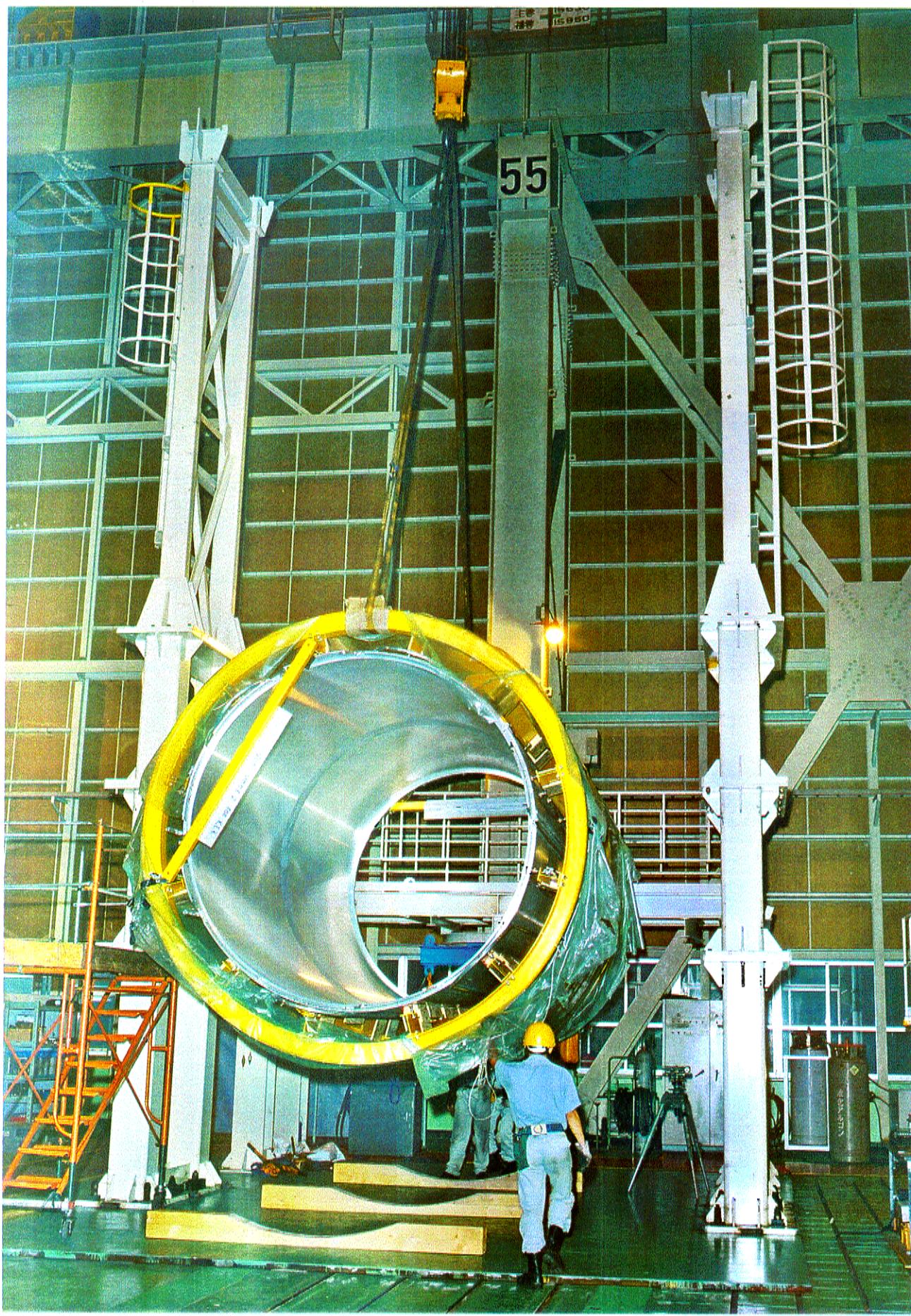


Payments for CMS Construction





ATLAS Solenoid - Toshiba



ATLAS Solenoid - Toshiba

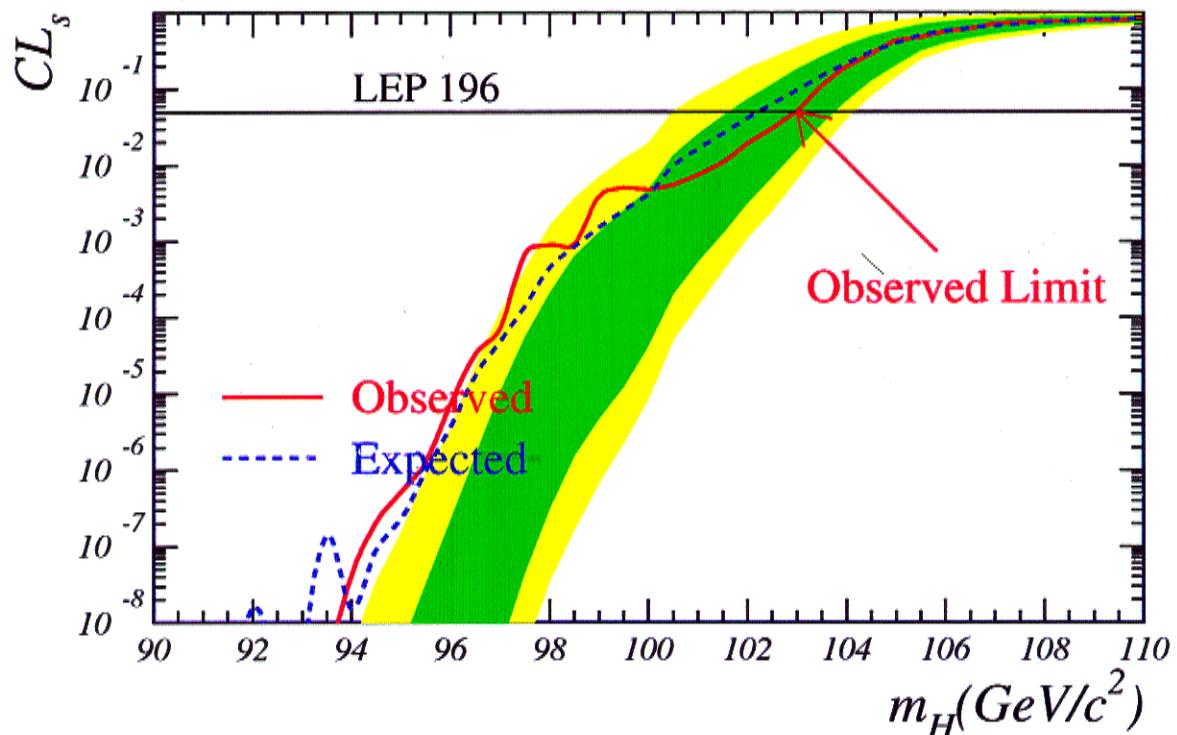


Point 5 - SX Roofing steelworks • September 17, 1999 - CERN ST-CE

The SM Higgs

Standard Model Higgs Limit

To set limits on Higgs mass hypothesis, look at CL_s :



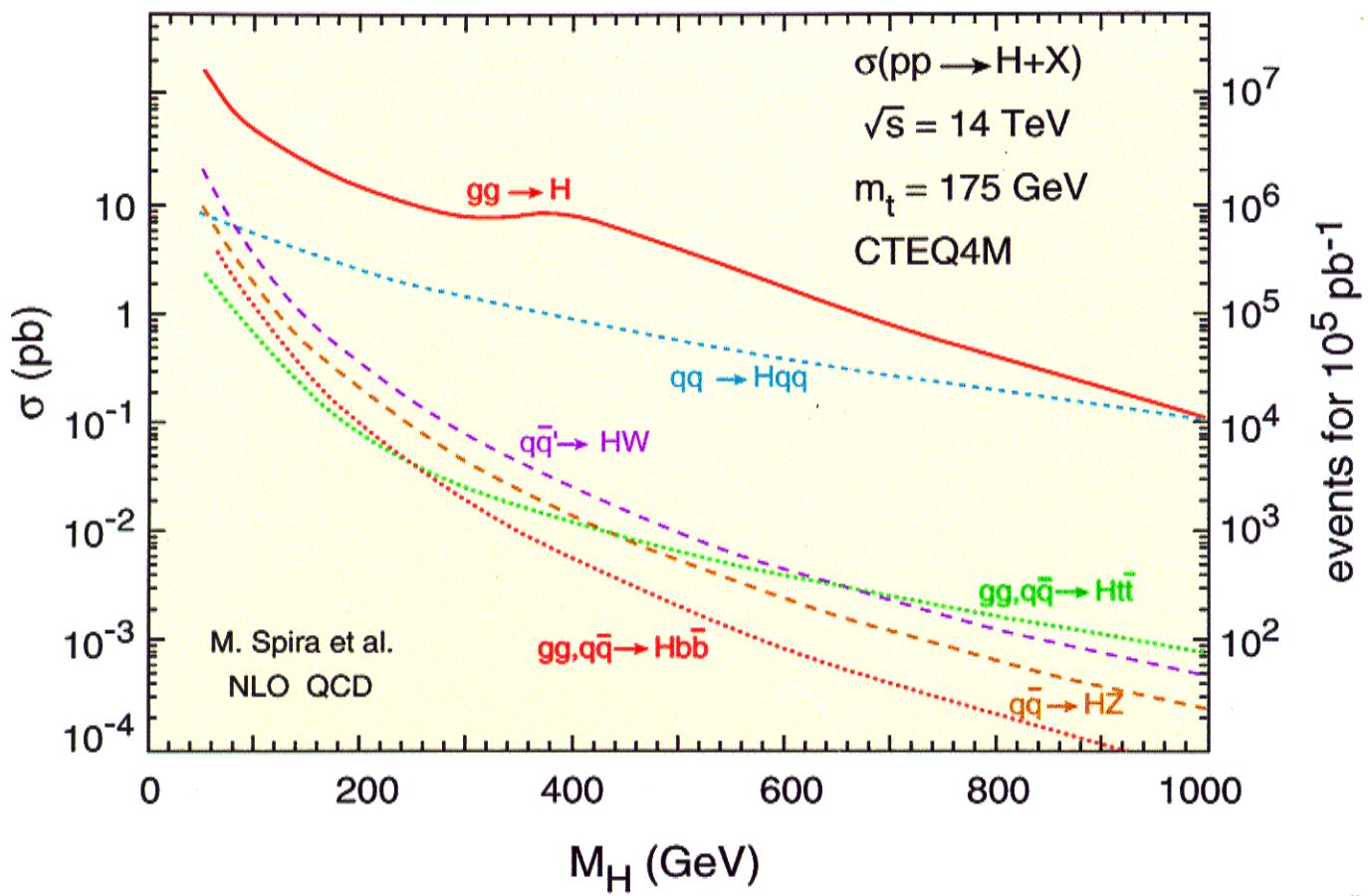
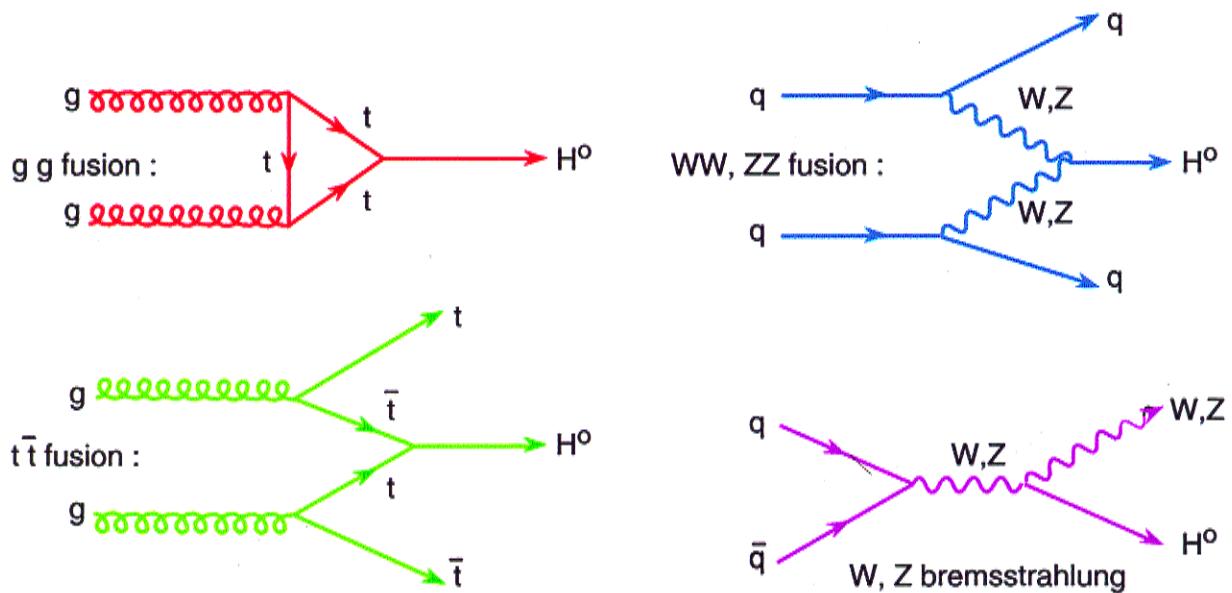
For all combination methods,
all $m_H \leq 102.6 \text{ GeV}/c^2$, $CL_s \leq 0.05$.

Therefore, a limit on the Higgs mass is set:

$m_H > 102.6 \text{ GeV}/c^2 @ 95\% \text{ C.L.}$

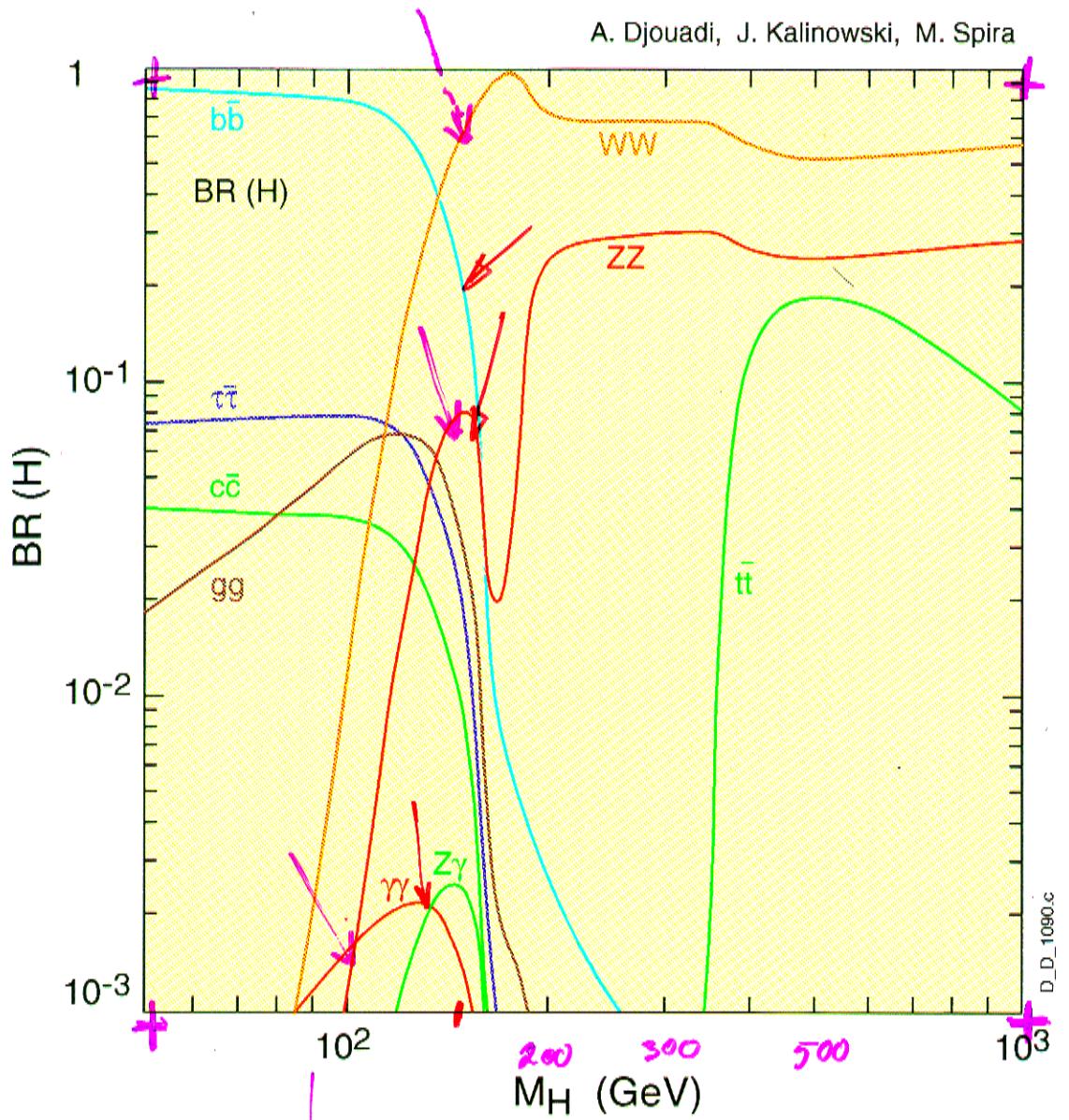
(with $102.3 \text{ GeV}/c^2$ expected)

H⁰ production at hadron colliders:



But: $\text{BR}(H \rightarrow Z^\circ Z^\circ \rightarrow 4l^\pm) = 1.4 \cdot 10^{-3}$
 $\text{BR}(H \rightarrow Z^\circ Z^\circ \rightarrow 4\mu^\pm) = 3 \cdot 10^{-4}$

Higgs Branching Ratios



the most promising
SM Higgs mass range

the MSSM h mass range

the SO₁₀ h mass range

S.M. Higgs Searches

- $H \rightarrow \gamma\gamma$ for $100 \leq m_H \leq 150$ GeV
in inclusive $H \rightarrow \gamma\gamma$ and in WH, ttH
- $H \rightarrow b\bar{b}$ for $90 \leq m_H \leq 120$ GeV
in WH, ttH
- $H \rightarrow ZZ^* \rightarrow 4\ell^\pm$ for $130 \leq m_H \leq 200$ GeV
- $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ for $140 \leq m_H \leq 180$ GeV
- $H \rightarrow ZZ \rightarrow 4\ell^\pm$ for $200 \leq m_H \leq 750$ GeV
- $H \rightarrow ZZ \rightarrow 2\ell^\pm + 2\nu$ for $0.5 \leq m_H \leq 1$ TeV
- $H \rightarrow WW \rightarrow \ell\nu jj$ for $m_H \approx 1$ TeV
- $H \rightarrow ZZ \rightarrow \ell\ell jj$ for $m_H \approx 1$ TeV

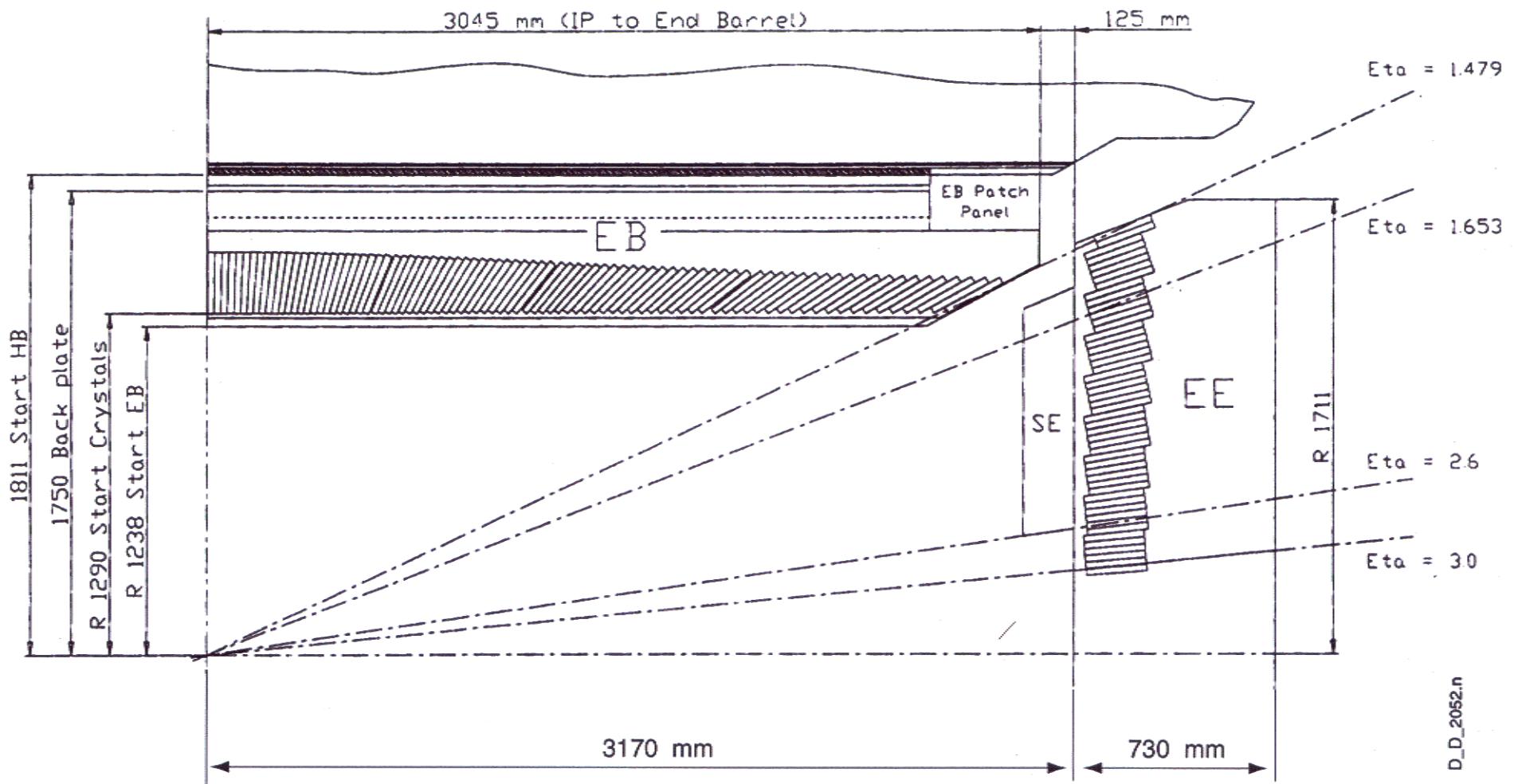
More recently :

$$H \rightarrow Z\gamma$$
$$gg \rightarrow gg H \xrightarrow{\text{H}} \gamma\gamma$$

H_{SM} → **WW**

D.D. 78

PbWO_4 crystal calorimeter of CMS

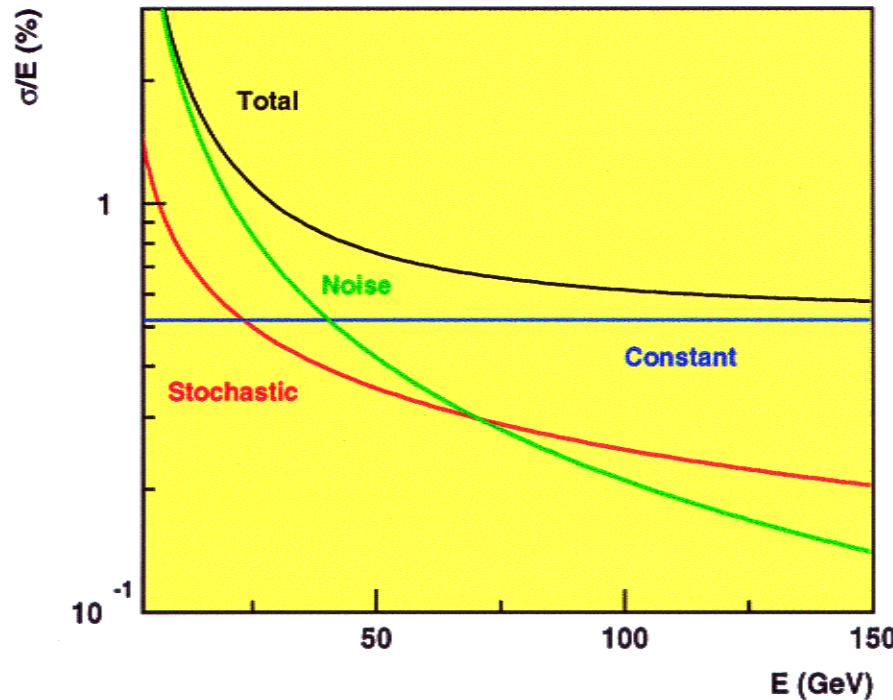


- Recent issues: barrel-end cap transition $\Rightarrow \leq 6\%$ of fiducial volume will reduced - quality response for H-jet, but OK for
- older issue: need for barrel preshower....

Lead tungstate (PbWO_4) crystal calorimeter

61200 PbWO_4 crystals of $22 \times 22 \times 230 \text{ mm}^3$ in the barrel ($|\eta| < 1.48$) and 16000 crystals of $29 \times 29 \times 220 \text{ mm}^3$ in the endcaps ($1.48 < |\eta| < 3.0$).

Design goal: $\Delta m_H < 1\%$ at $m_H = 100 \text{ GeV}$



Energy resolution:

- Crystal light yield + photodetector (APD)
→ **Stochastic term 2.5%**
- Crystal non-uniformity + calibration
→ Constant term 0.52%
- Readout electronics
→ **Noise 210 MeV/5x5 array**

H → γγ

A $\gamma\gamma$ mass resolution of ≈ 1 GeV at $m_{\gamma\gamma} = 100$ GeV is needed

NLO cross sections

with kinematic cuts ($p_t^{\gamma 1} > 40$ GeV, $p_t^{\gamma 2} > 25$ GeV, $|\eta| < 2.5$)
and isolation

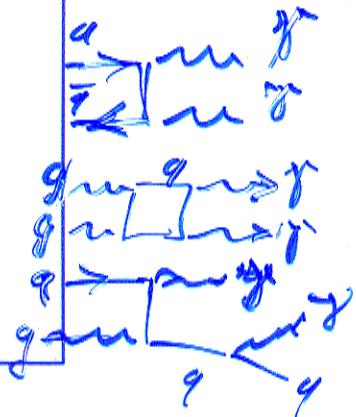
H → γγ, $m_H = 100$ GeV, $\sigma * BR :$ 86.1 fb

Irreducible $\gamma\gamma$ backgrounds (at $m_{\gamma\gamma} = 100$ GeV):

qq → γγ 92 fb / GeV

gg → γγ 167 fb / GeV

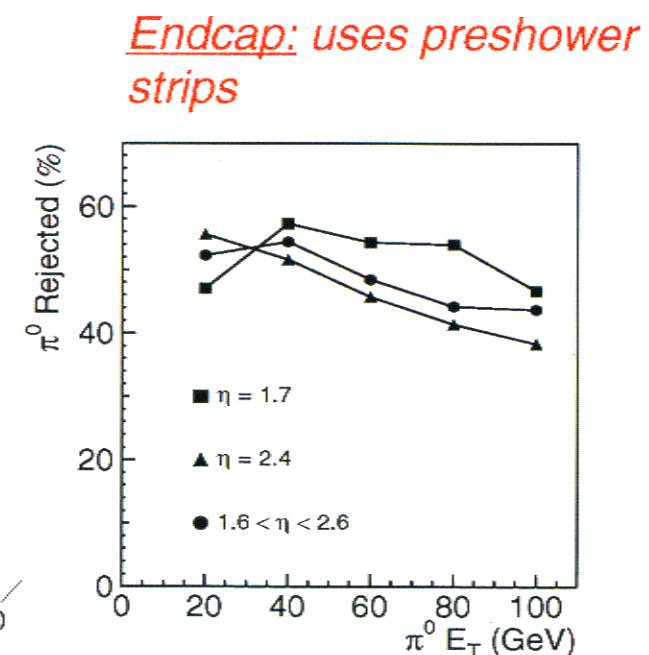
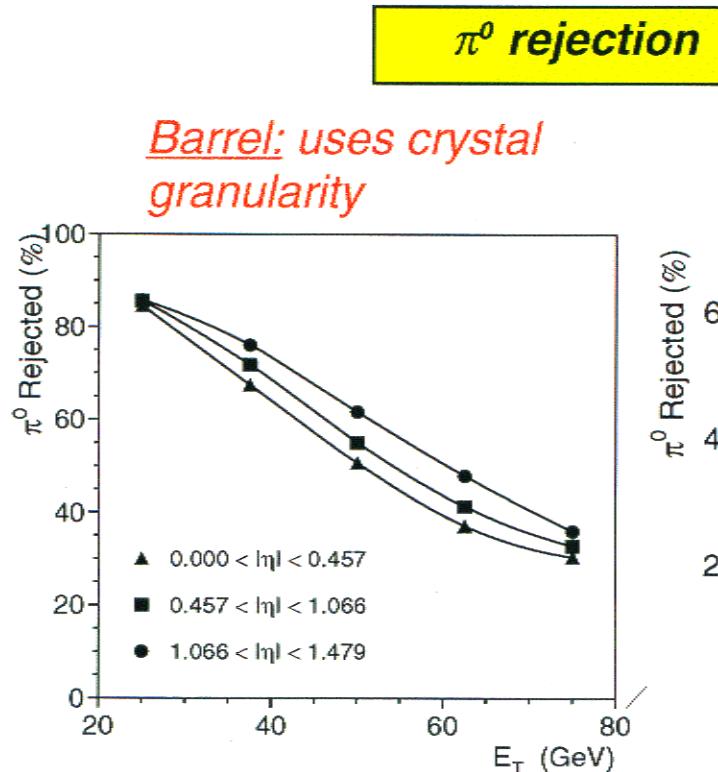
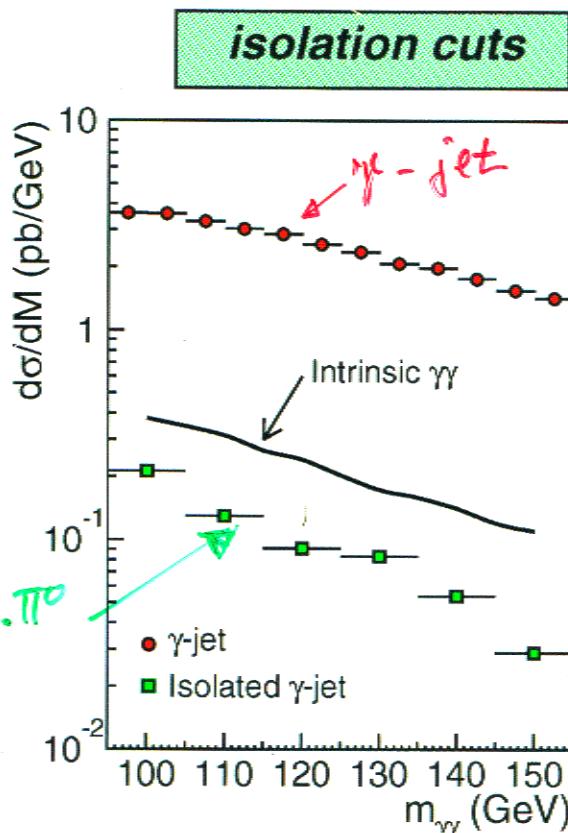
Isolated bremstrahlung 120 fb / GeV



Main reducible background from γ+jet (with "jet" = " $\pi^0 \rightarrow \gamma\gamma$ ")
 $\lesssim 15\%$ of irreducible $\gamma\gamma$ background

Reducible background

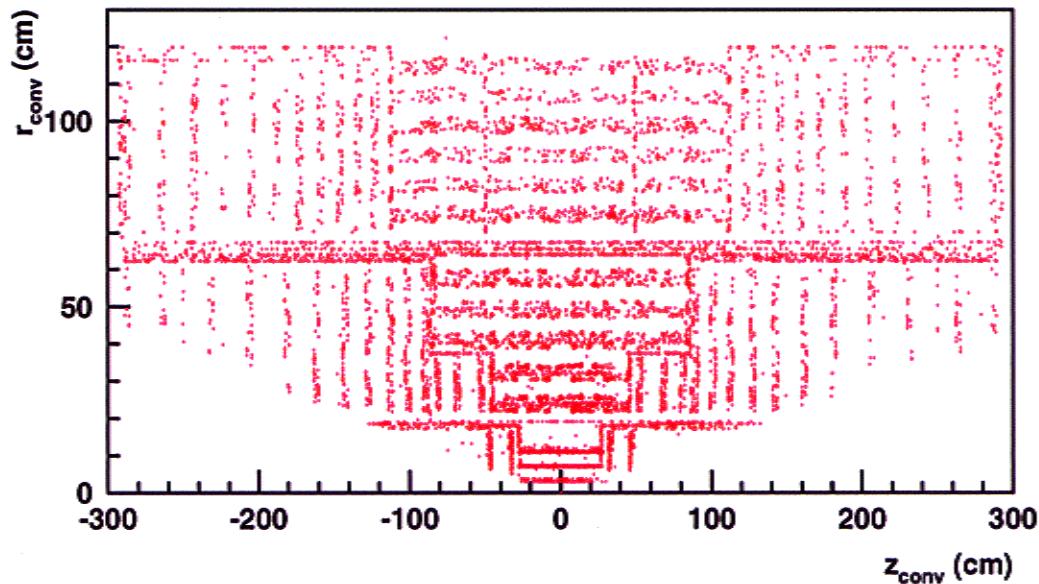
- Predominantly $\gamma + \text{jet}$, where most of jet E_T is carried by a π^0 which is reconstructed as a photon



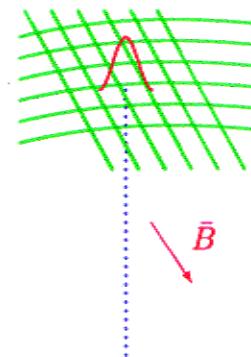
Rejection power shown for 90% γ efficiency

After isolation and π^0 rejection jet background below $m_H = 100$ is $\approx 15\%$ of intrinsic $\gamma\gamma$ background

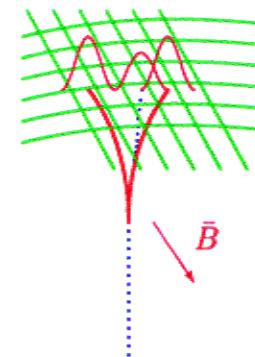
Photon conversions



Normal photon



Converted photon

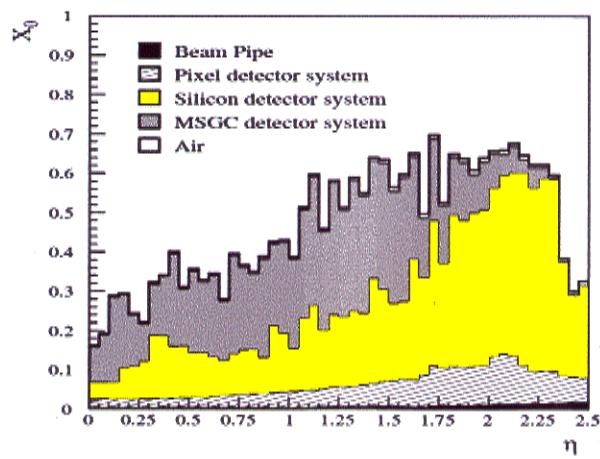


1. Conversion identification in the tracker

- measurement of the invisible conversions with the same precision as the normal photons

2. E_{γ} measurement with a similar precision for normal photons and visible (identified) conversions.

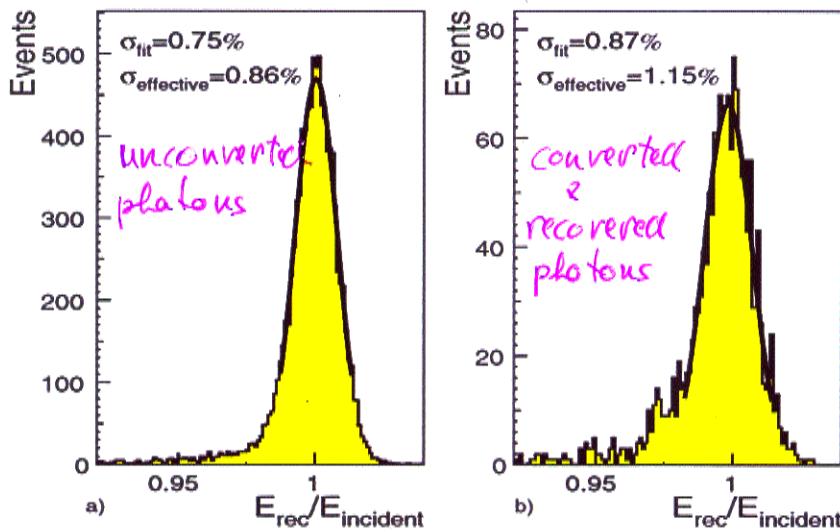
Recovery of conversions



Tracker material, in radiation lenghts, between the interaction point and the ECAL as a function of η

For $H \rightarrow \gamma\gamma$, $m_H = 100$ GeV:

Photons converted: 23.8% in Barrel, 34.9% in Endcaps



In barrel 75.4% of the visible conversions reconstructed, 95.4% of all photons

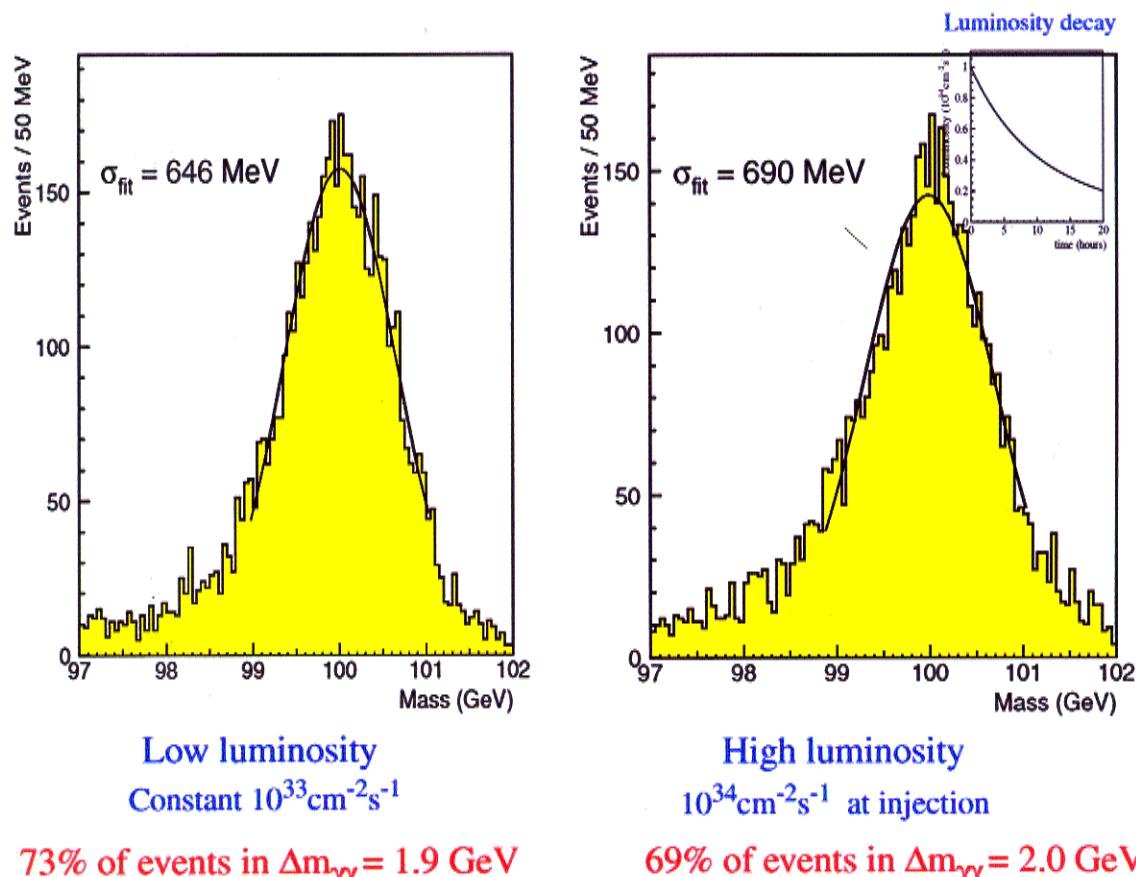
In endcaps 64.5% of the visible conversions reconstructed, 90.7% of all photons



Higgs mass reconstruction in $H \rightarrow \gamma\gamma$

Energy resolution assumed

in barrel: $2.7\%/\sqrt{E} + 0.55\% + 155 \text{ MeV}(210 \text{ MeV})/E$ for low (high) L
in endcap: $5.7\%/\sqrt{E} + 0.55\% + 770 \text{ MeV}(915 \text{ MeV})/E$ for low (high) L



Single photon reconstruction efficiency:

Fiducial area cuts within $|\eta| < 2.5$ 92.5%

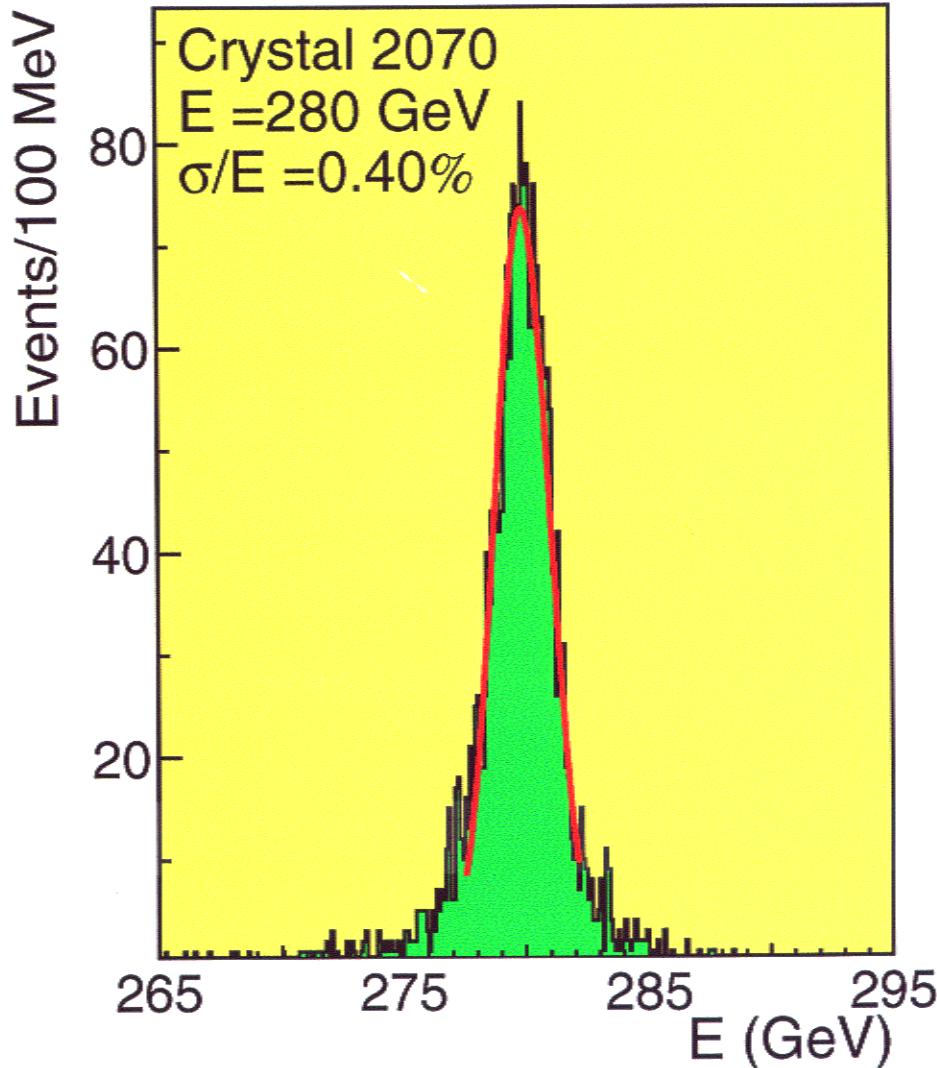
Unrecoverable conversions 94%

Isolation cuts 95%

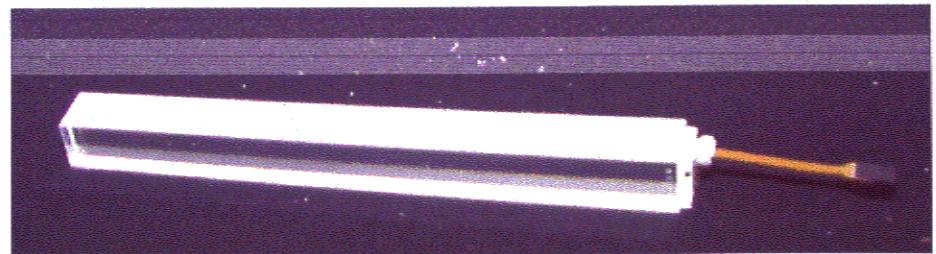
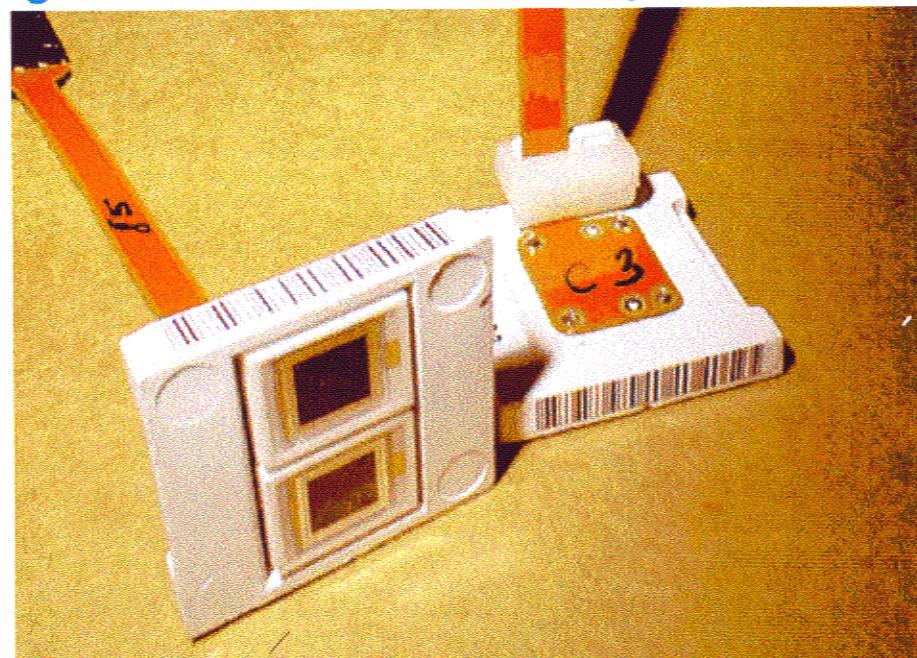
π^0 rejection algorithms 90%

Total reconstruction efficiency 74.5%

Test Beam Results 1999: Barrel



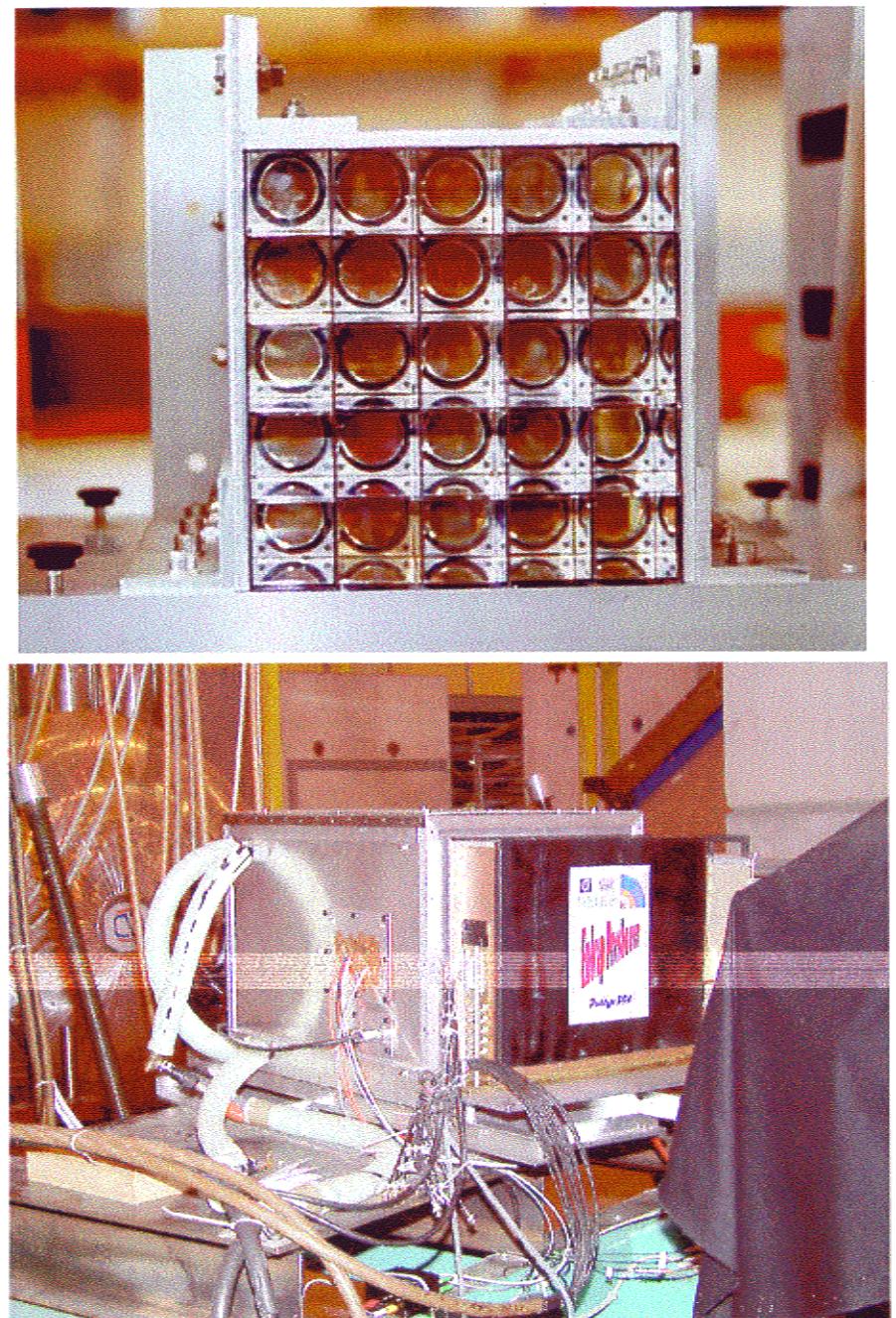
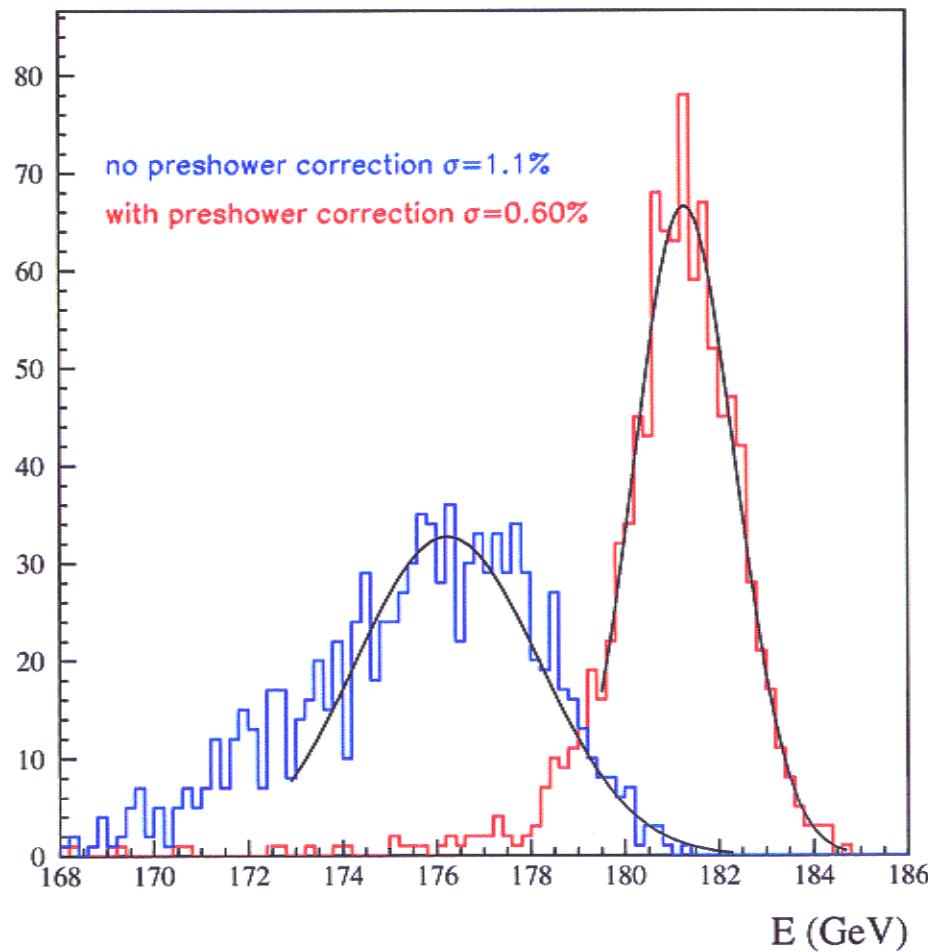
Two APDs 5 x 5 mm surface mounted
in a supporting structure (capsule)
glued at the rear of the crystal



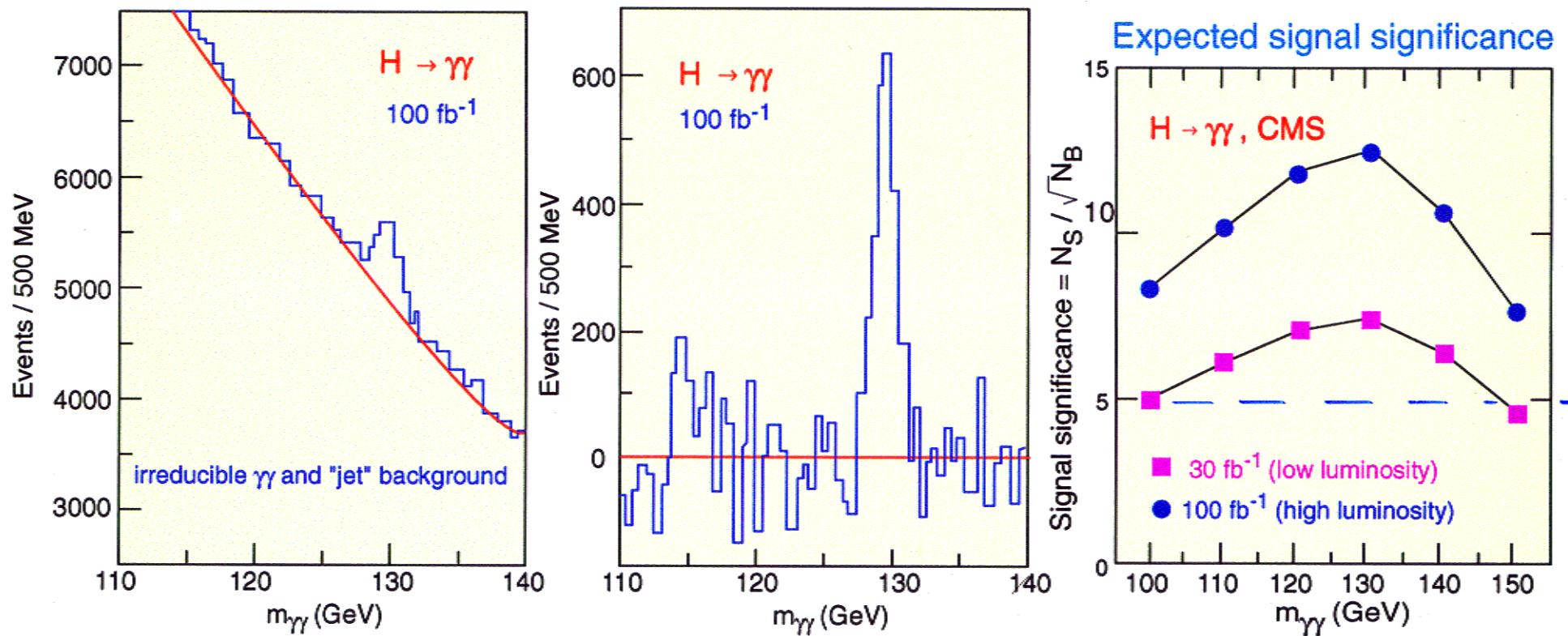


Test Beam Results 1999: Endcap

180 GeV Electrons at normal incidence



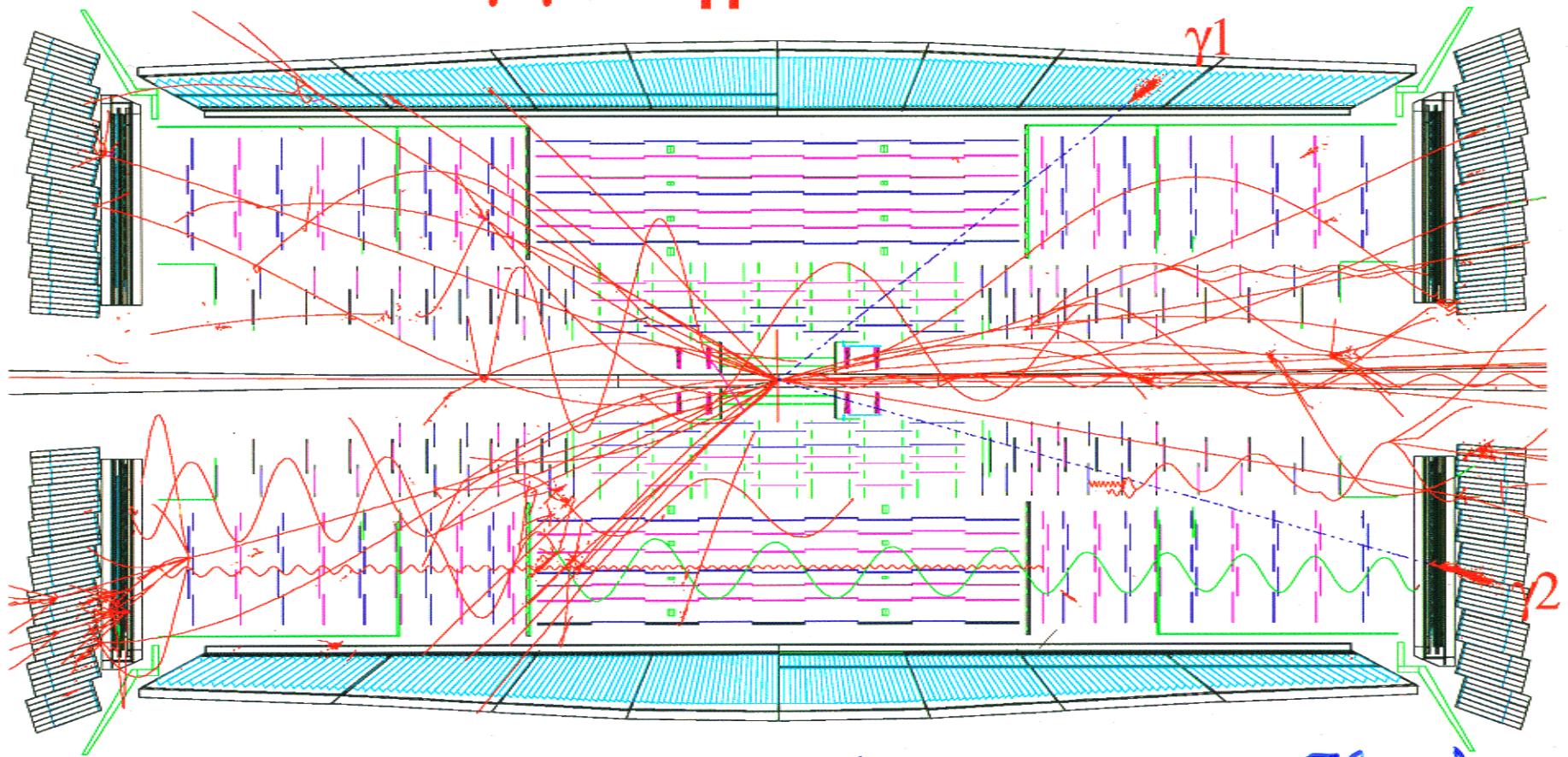
$H_{SM} \rightarrow \gamma\gamma$ in CMS PbWO₄ calorimeter



D_D_1205c.mod

Problems with p_t^H
and the efficiency of vertex designation algorithm
in $H \rightarrow \gamma\gamma$

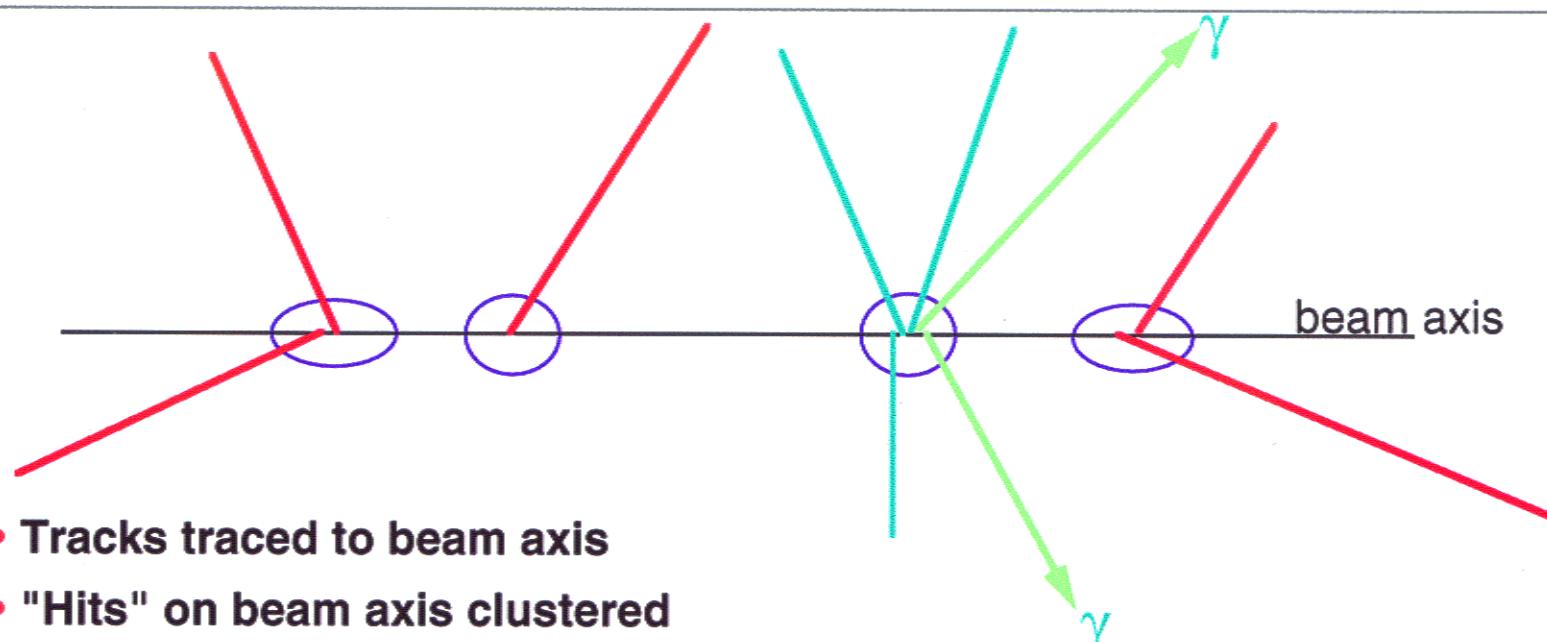
$H \rightarrow \gamma\gamma, M_H = 100 \text{ GeV}$



$\gamma\gamma$ mass resolution: $\frac{\delta M}{M} = \frac{1}{2} \left(\frac{\delta E_1}{E_1} \oplus \frac{\delta E_2}{E_2} \oplus \frac{\delta \ell}{\ell g(\ell/E_2)} \right)$

→ at high ℓ instantaneous, if vertex not known ($\ell_{\text{vtx}} \approx 5.3 \text{ cm}$) $\delta \ell$ -term dominates error δM i.e. $\delta M_{\ell=\text{vtx}} \approx 10 \text{ GeV}$ → develop methods to find vertex - or build preshower to measure ℓ direction!

Track algorithm



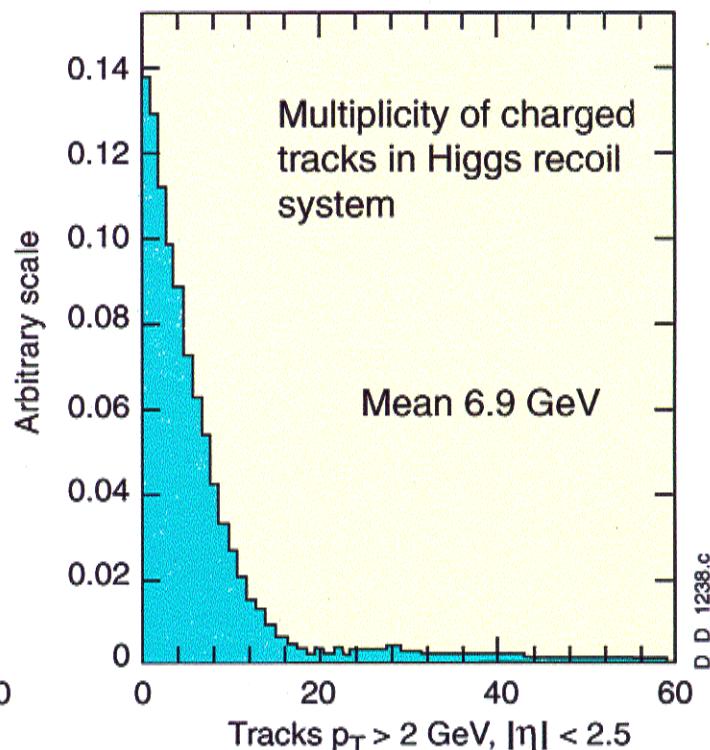
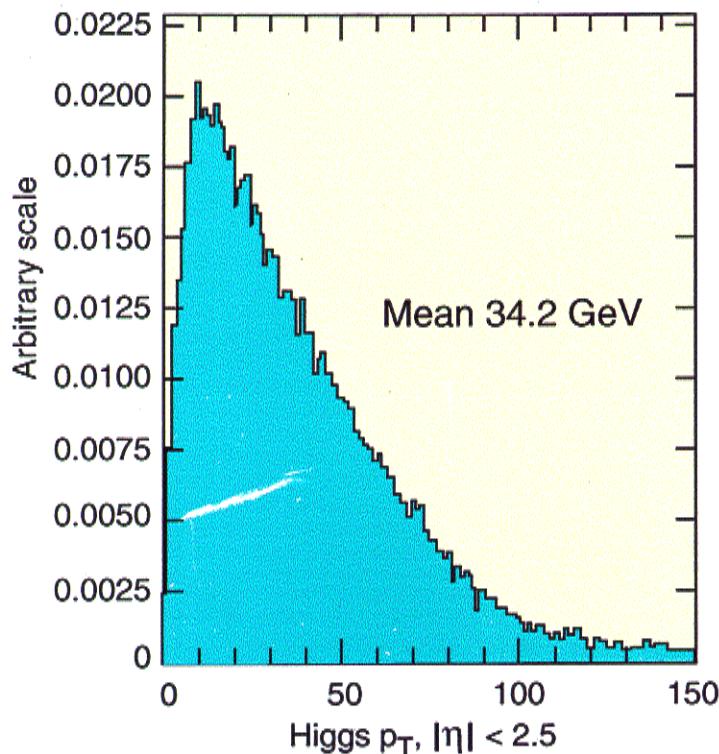
- Tracks traced to beam axis
- "Hits" on beam axis clustered
- Cluster with largest number of tracks taken as Higgs vertex
- Algorithm involves choice of p_T threshold and ϕ cut
 - At present choice is made on the basis of luminosity
 - Choice on the basis of bunch crossing activity perhaps better — under development
- Important parameters are σ_z (vertex) and $\varepsilon_{\text{track}}$
 - We assume σ_z (vertex) = 2 mm, and $\varepsilon_{\text{track}} = 95\%$ but 5 mm and 80% are OK

Higgs production mechanisms considered

PYTHIA 5.7 + Kunszt and Stirling

| Mechanism | $\sigma \cdot B$ | % | $\langle p_T \rangle$ | $\langle N_{\text{tracks}} > 2 \text{ GeV} \rangle$ |
|---------------------------|------------------------------|------|-----------------------|---|
| $gg \rightarrow H$ | $1.5 \times 38.9 \text{ fb}$ | 81.9 | 31.1 GeV | 4.48 |
| $WW / ZZ \rightarrow H$ | 7.4 fb | 10.4 | 53.2 GeV | 4.96 |
| $gg \rightarrow tt H, VH$ | 5.5 fb | 7.7 | 93.0 GeV | 31.13 |
| Total | 71.25 fb | - | 34.2 GeV | 6.9 |

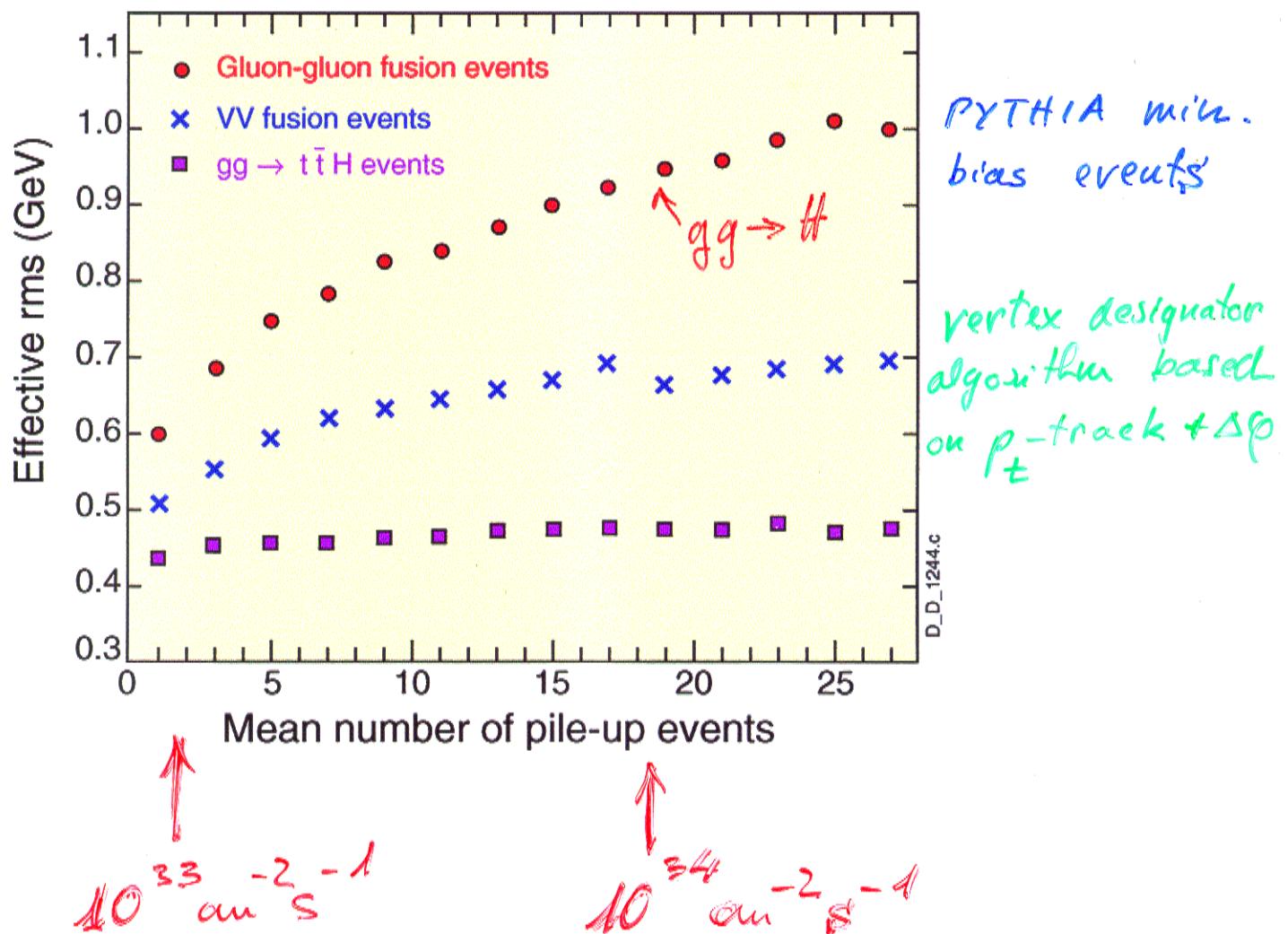
Distributions of Higgs p_T and multiplicity of charged tracks with $p_T > 2 \text{ GeV}$



PYTHIA 5.7 !

H → γγ mass reconstruction

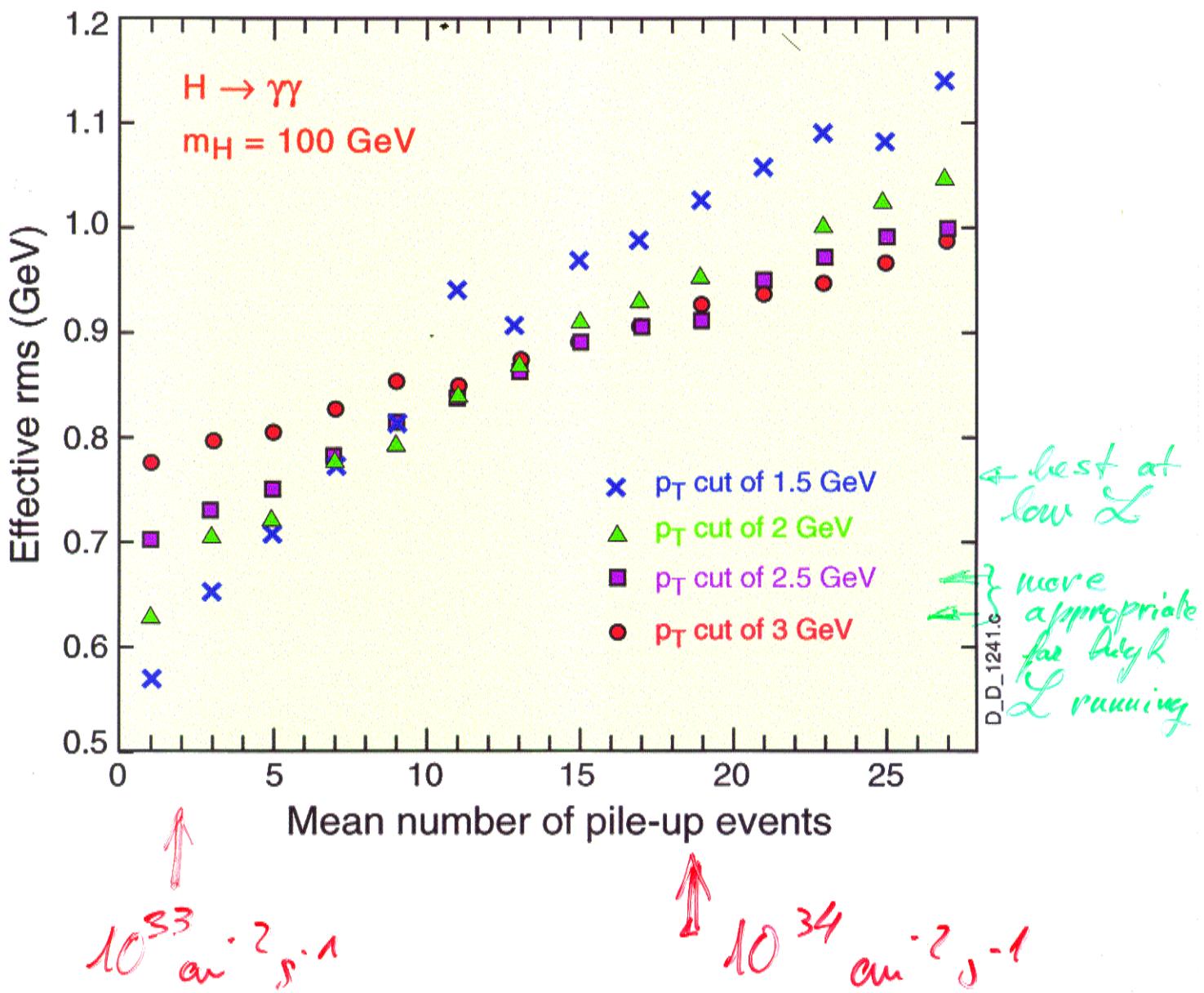
Effective rms as a function of the mean number of pile-up events for each of Higgs production mechanisms considered individually.



Optimisation of vertex-discriminator algorithm versus luminosity

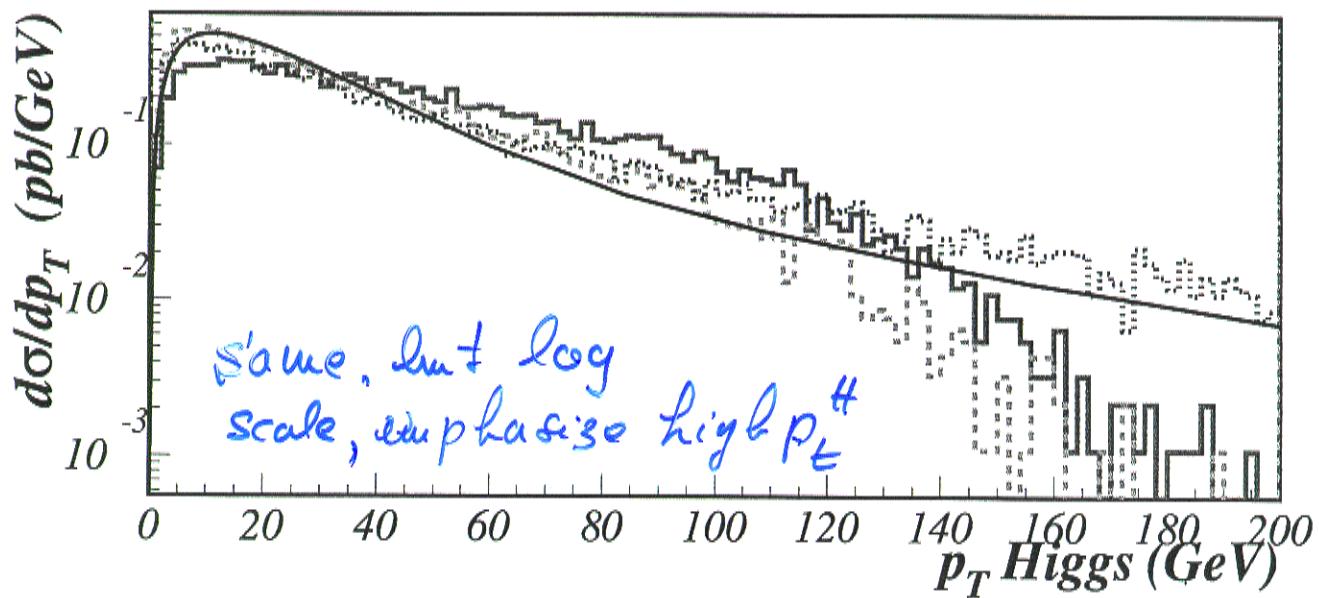
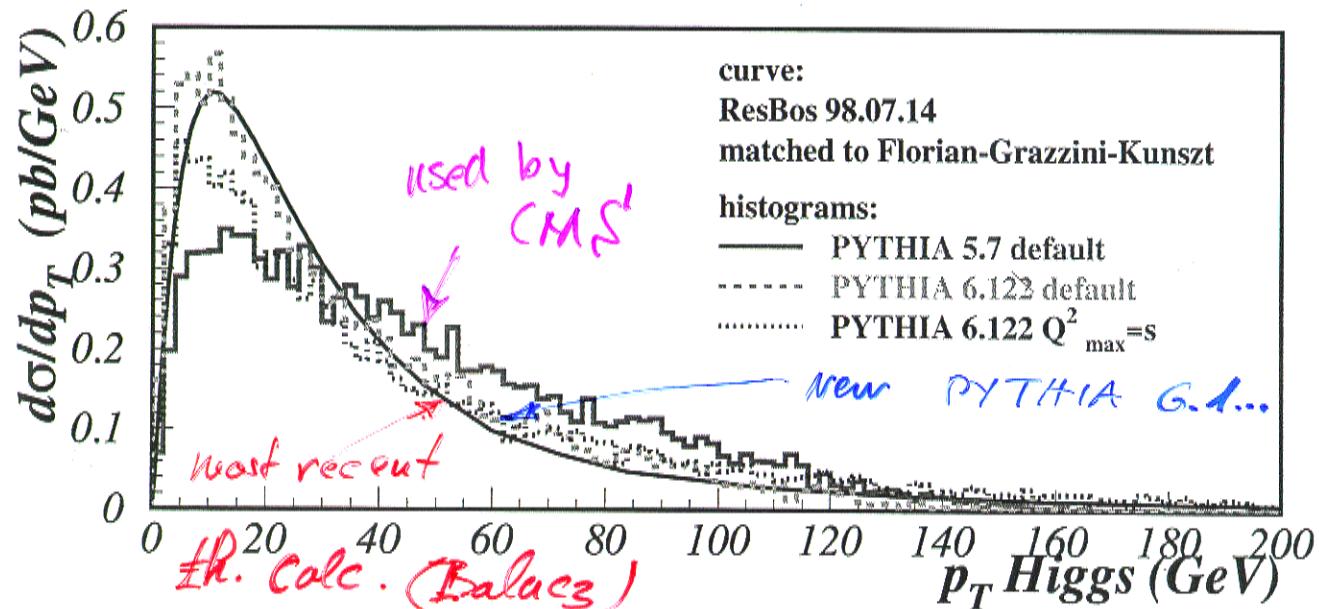
$H \rightarrow \gamma\gamma$ reconstruction

Effective rms as a function of the mean number of pile-up events for 4 different p_T cuts on tracks



The bad news:
 p_T^H from $gg \rightarrow H$ became significantly
 softer recently:

p_T of Higgs in gg fusion, $m_H = 150$ GeV, CTEQ4M

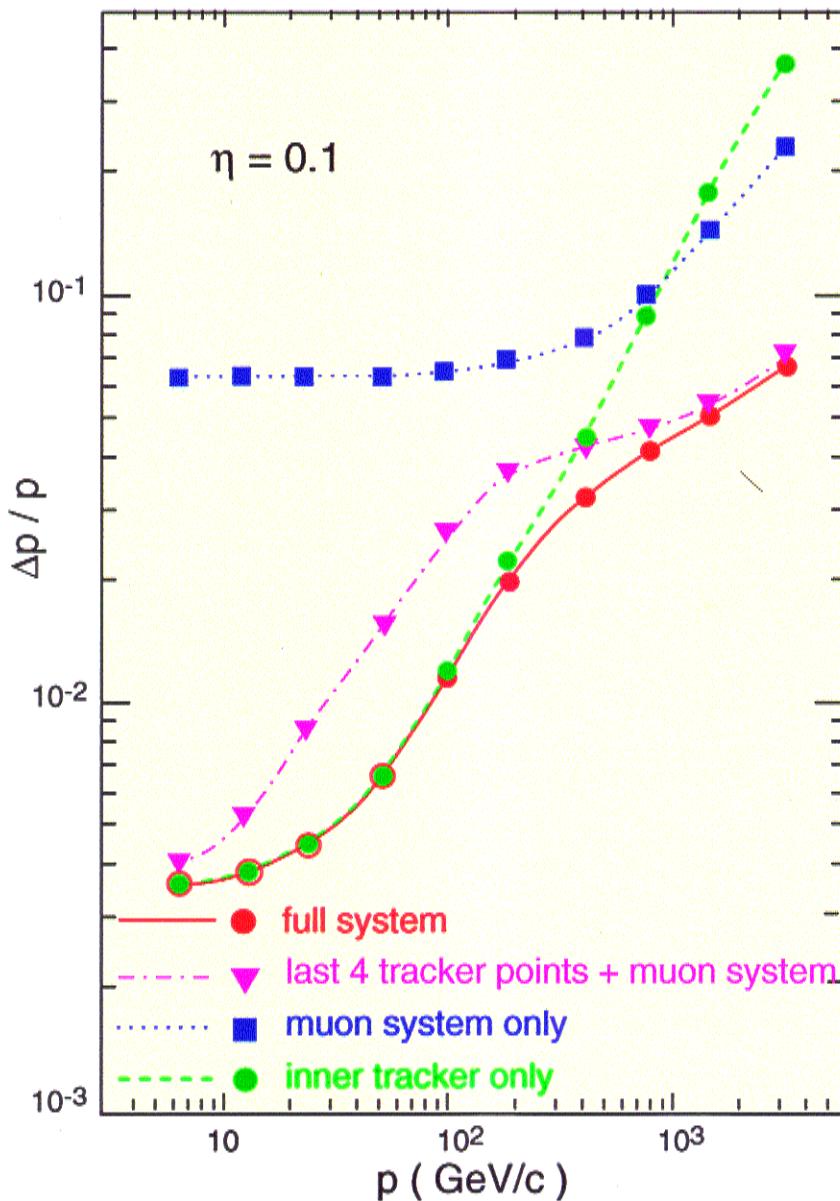


→ loss of efficiency of vertex-clustering
 algorithm or loss of preselection of hard tracks in $H \rightarrow \gamma\gamma$ events

H → Z*Z, ZZ

D.D.89

CMS muon momentum resolution

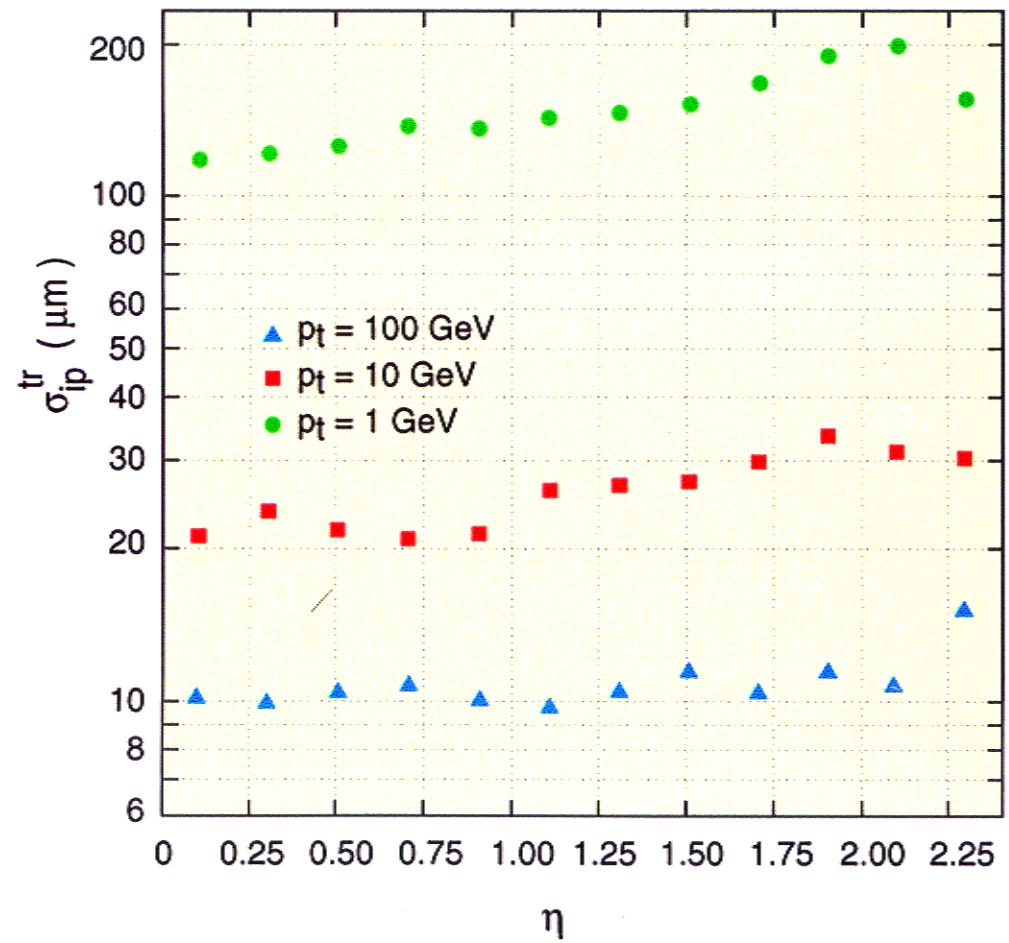
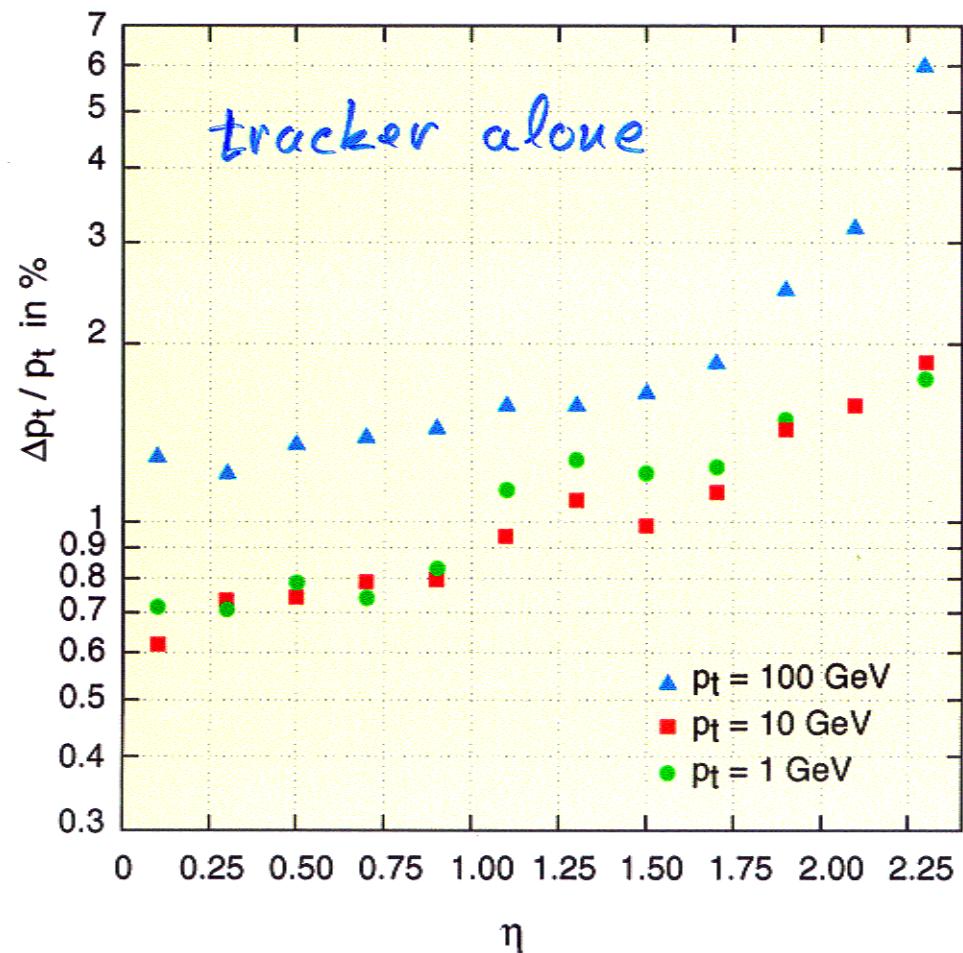


- 16 Tm of bending power in barrel, including return yoke
best precision for muons connecting tracker and muon system measurements
- outer muon system essential for triggering

Momentum resolution in CMS

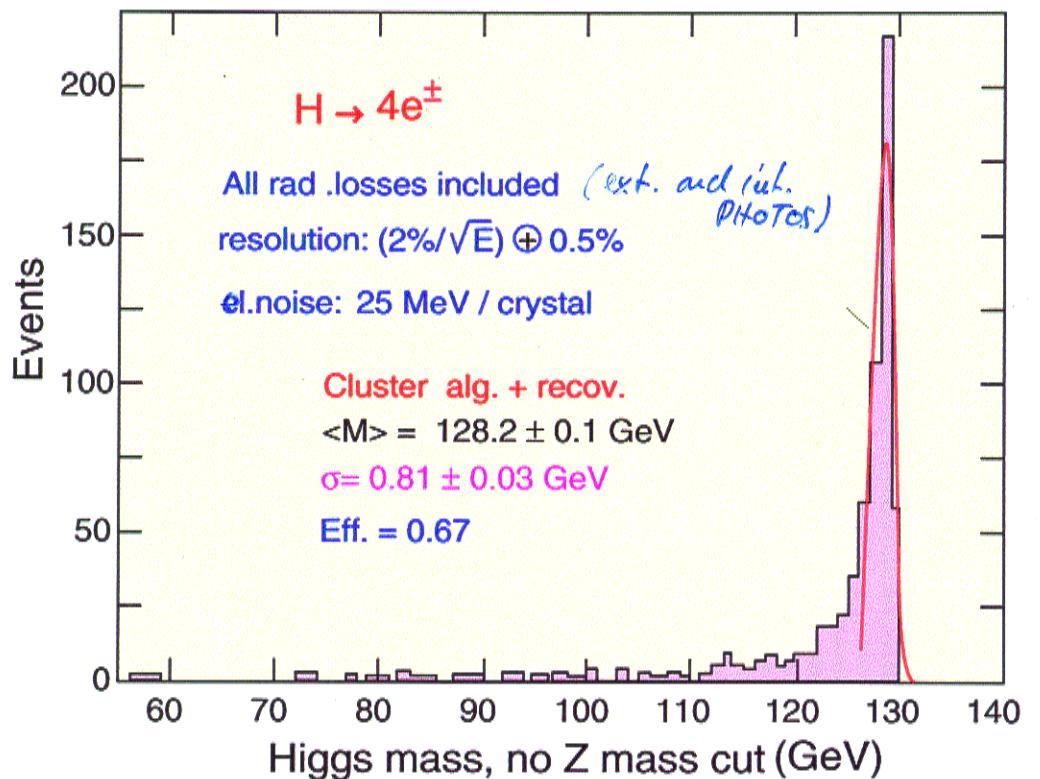
Impact parameter resolution in CMS in transverse plane

With full pattern recognition and track reconstruction in low luminosity tracker configuration



Electron reconstruction in CMS

$H \rightarrow ZZ^* \rightarrow 4e$, $M_H = 130$ GeV,



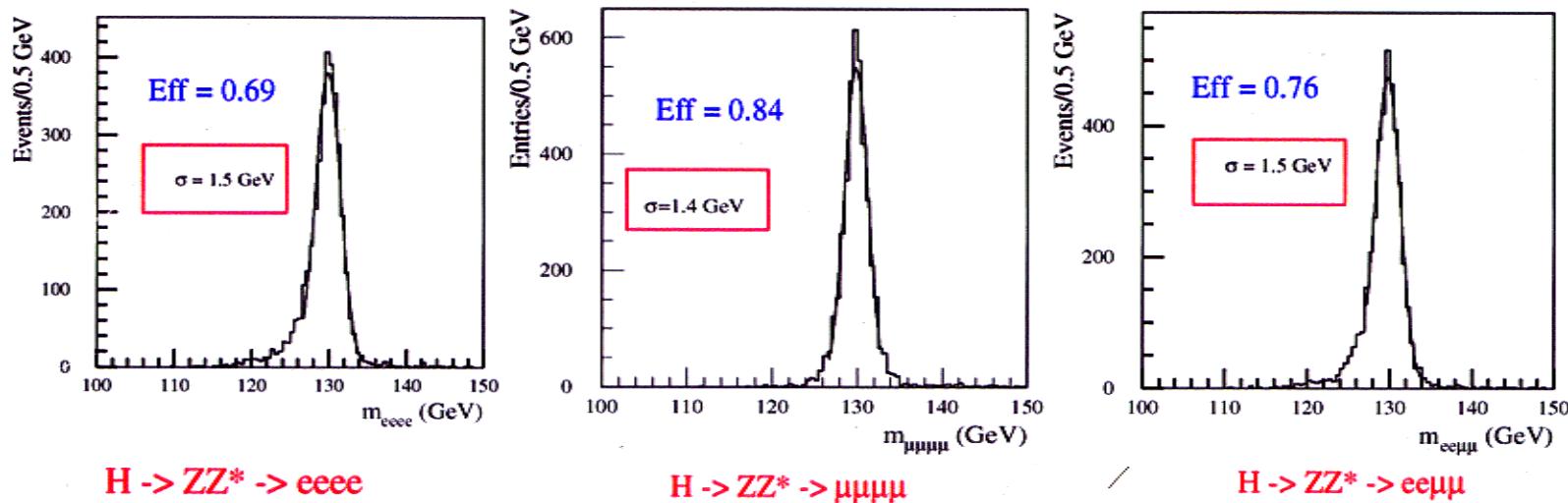
Crystal calorimeter provides excellent resolution

The main difficulty in CMS is electron reconstruction efficiency because of material in the tracker inducing bremsstrahlung, combined with the 4T field

H \rightarrow ZZ* \rightarrow 4l in ATLAS

Higgs-boson mass reconstruction at low luminosity with full detector simulation
including internal and external bremstrahlung

2 leptons, $p_t > 20$ GeV and 2 leptons, $p_t > 7$ GeV, $|\eta| < 2.5$
Z mass constraint for one pair ($\Delta m = 40$ GeV to 12 GeV)
remaining pair with $m > m_{34}$ ($m_{34} = 15$ GeV to 60 GeV)



Lepton isolation and impact parameter cuts against the reducible $t\bar{t}$ and $Zb\bar{b}$ backgrounds

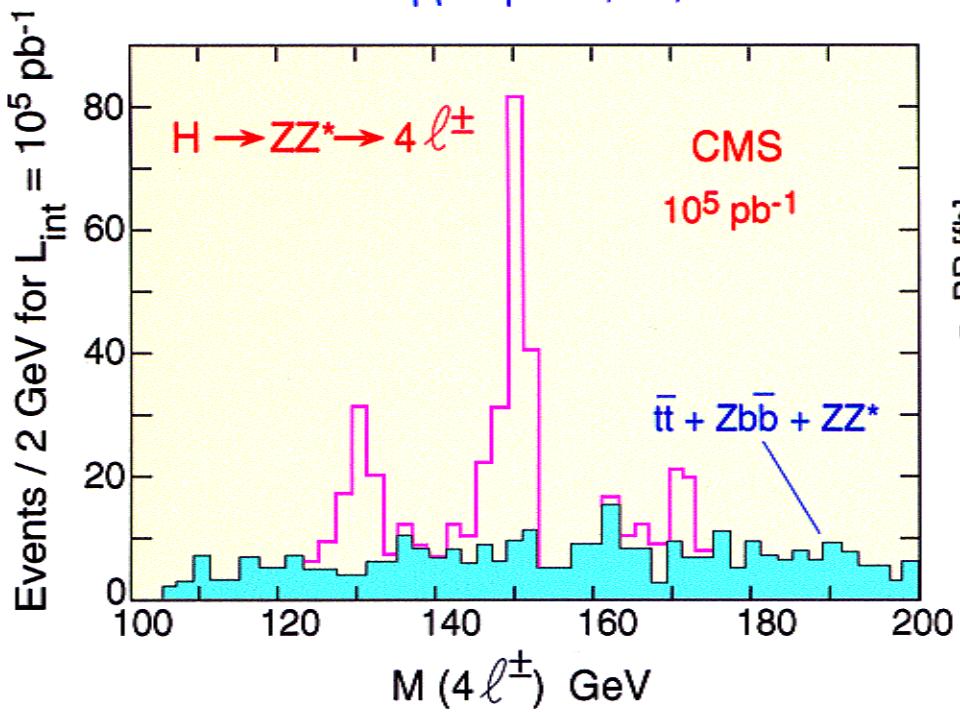
Rejection from isolation cuts: ~110 against $t\bar{t}$, ~30 against $Zb\bar{b}$, signal efficiency 90% (75%)

Rejection from impact parameter cuts: ~12 against $t\bar{t}$, ~5.5 against $Zb\bar{b}$, signal efficiency 90% (70%)

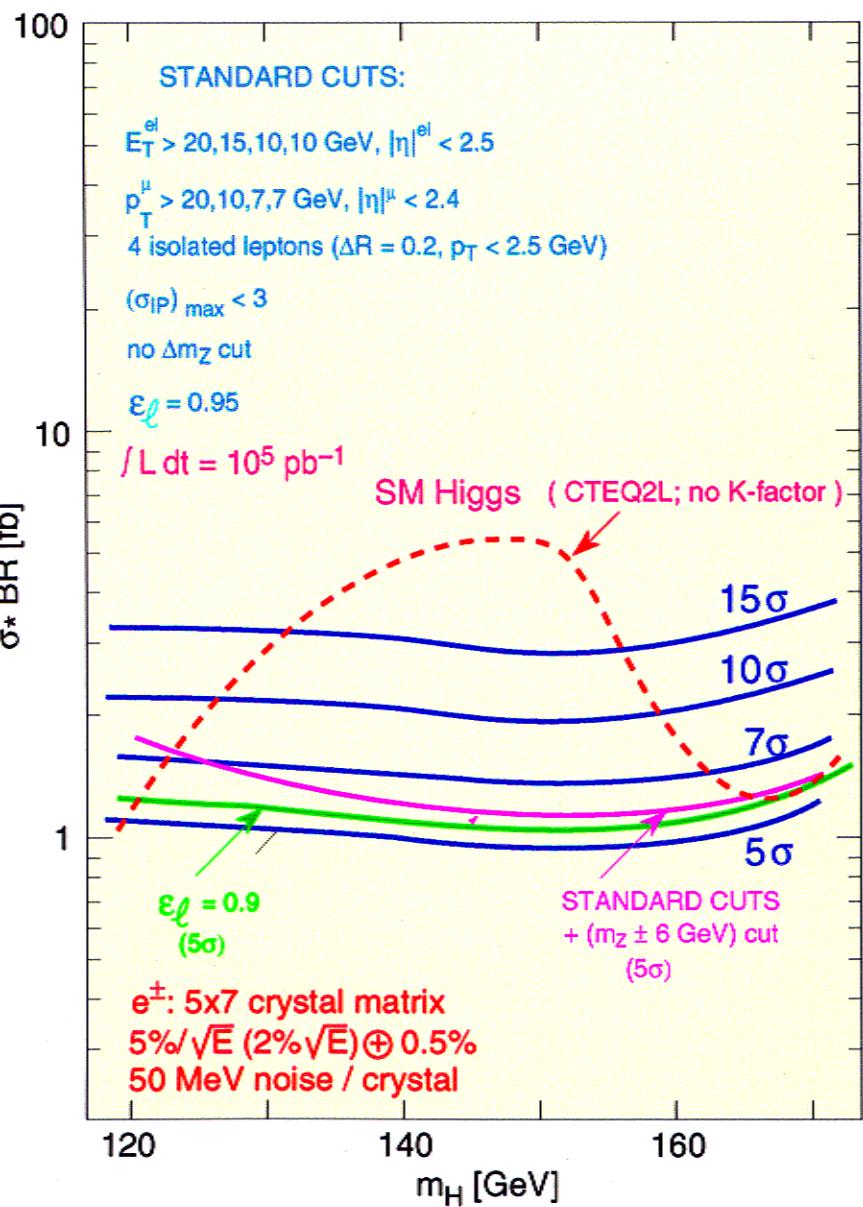
$H \rightarrow ZZ^* \rightarrow 4\ell^\pm$ in CMS

$\sqrt{s} = 14$ TeV, $m_{top} = 174$ GeV, CTEQ2L str. func.

$E_T^e > 20, 15, 10, 10$ GeV; $p_T^\mu > 20, 10, 5, 5$ GeV;
 $|\eta^{e,\mu}| < 2.5, 2.4$;

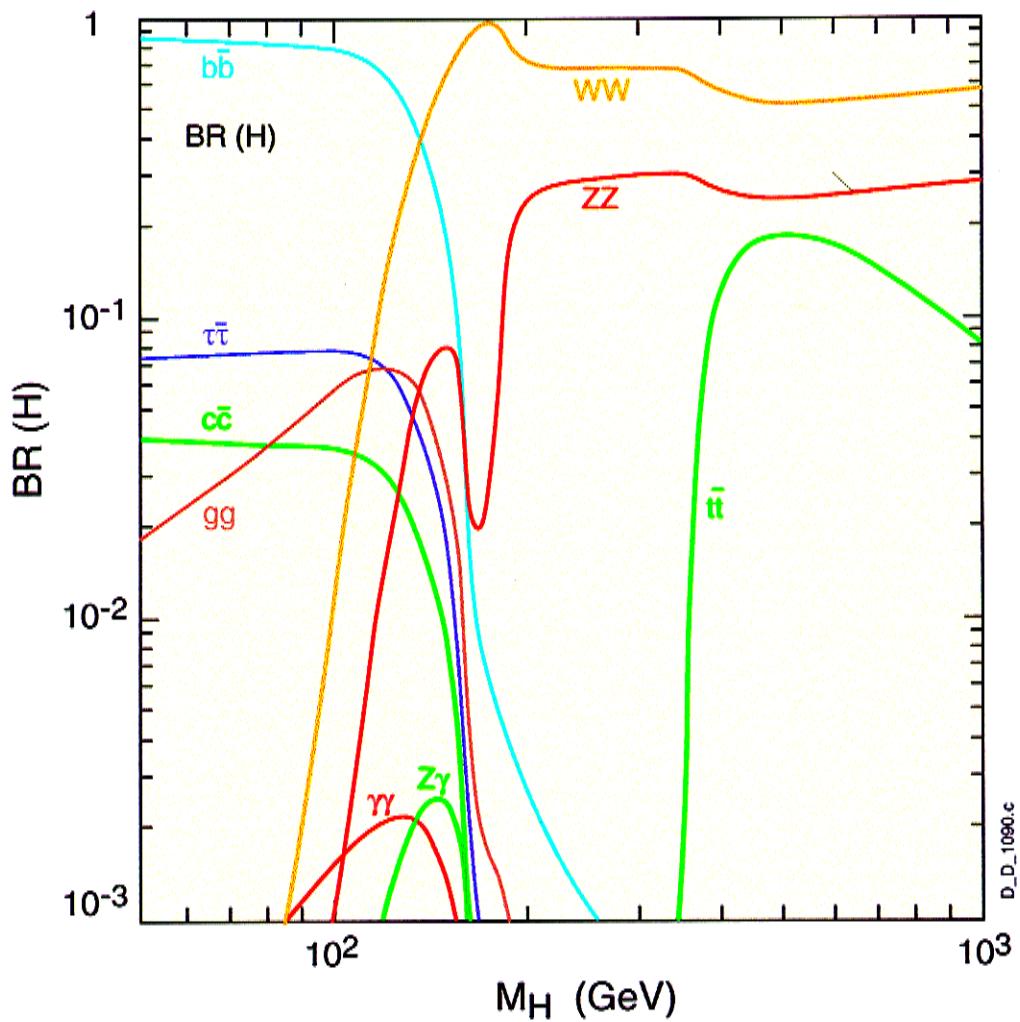


$\sigma^* BR$ required to give specified significance $n \sigma$



Higgs Branching Ratios

A. Djouadi, J. Kalinowski, M. Spira



$H_{SM} \rightarrow WW \rightarrow l\bar{v}l\bar{v}$

for $m_H \sim 170$ GeV

$H_{SM} \rightarrow WW \rightarrow l\nu l\nu$

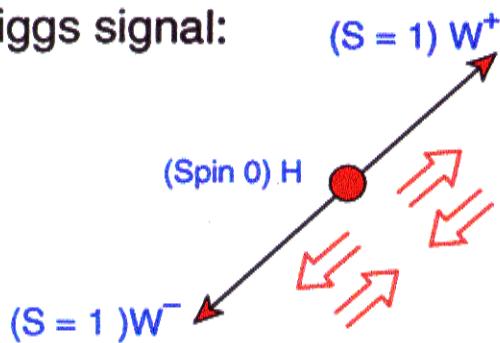
for $m_H \sim 170$ GeV

$$H \rightarrow WW \rightarrow \ell\nu\ell\nu \text{ for } m_H \simeq 2m_W$$

To suppress irreducible WW background
use W^+W^- spin correlations !

a) Spin orientations

Higgs signal:



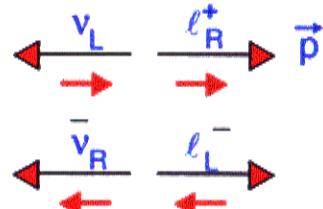
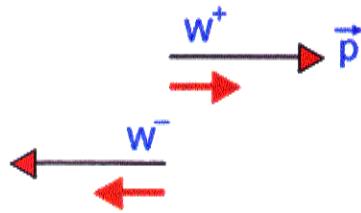
Background:

$$q\bar{q} \rightarrow W^+W^-$$

$$W_tW_L, W_LW_t$$

$$W_tW_t, W_LW_L$$

b) $W^\pm \rightarrow \ell^\pm \nu$ decays (V-A)



Higgs signature :

$\ell^+\ell^-$ pair with small opening angle

if $p_t(W) \ll M_W$
(for $M_H \leq 180$ GeV)

2. Selection: W^+W^- Spin correlations!

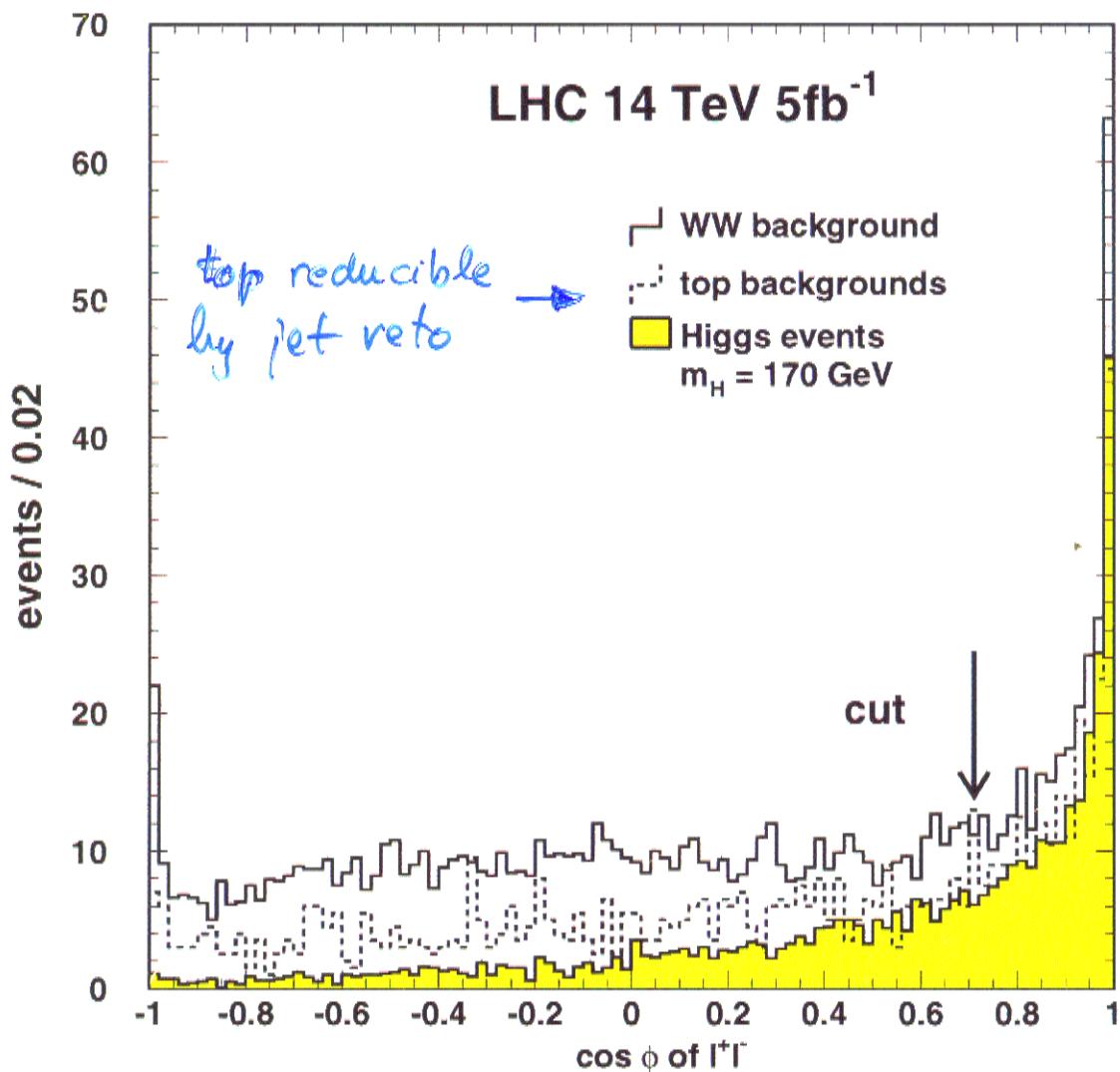
small $\ell^+\ell^-$ opening angle:

$$\cos \phi_{plane} > 0.71 (\phi_{plane} = 10^\circ - 45^\circ)$$

for 5 fb^{-1} luminosity:

Signal rate: ≈ 300 events ($M_H = 170 \text{ GeV}$)

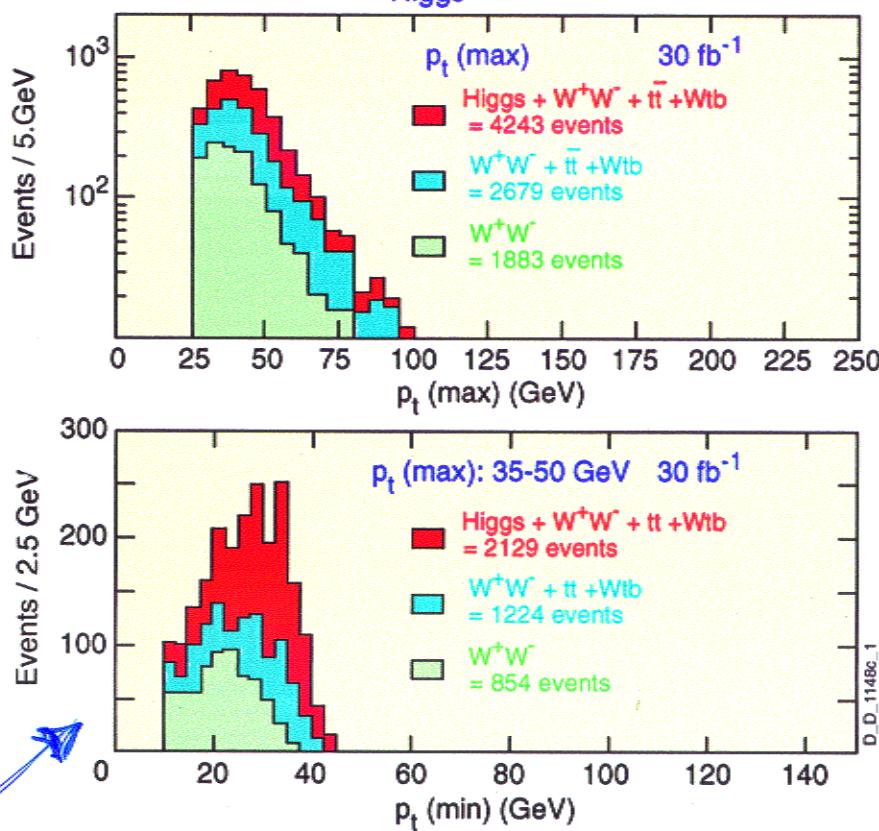
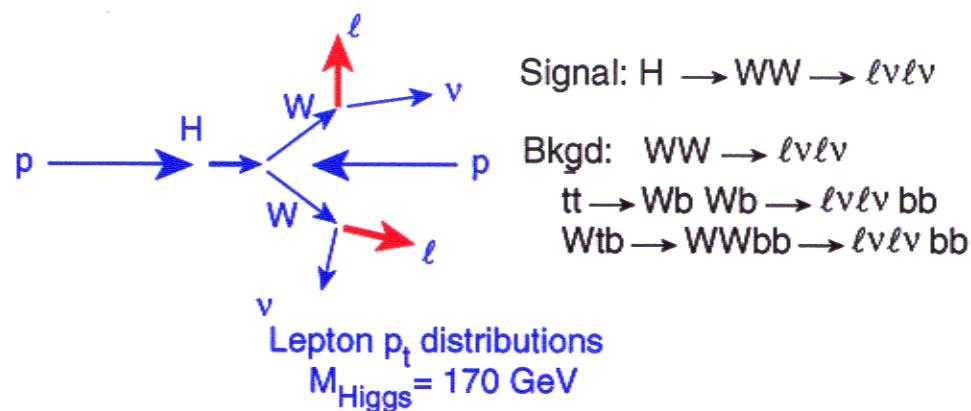
background: $\approx 600 \pm 25$ (stat.) $\pm 30\text{-}60$ (assuming 5–10% syst. error)



ϕ = relative azimuthal angle
- in transverse plane

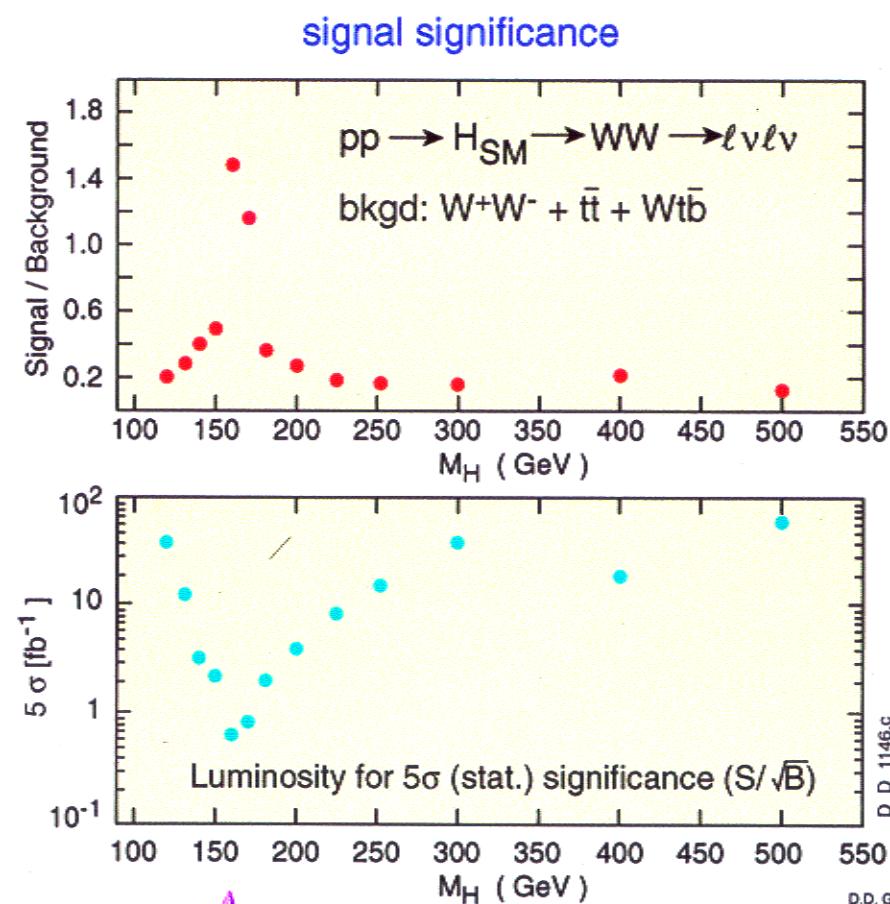
Dirtier
Greiner

$H_{SM} \rightarrow WW \rightarrow \ell\nu\ell\nu$



use rate and shape to determine M_H

↳ reducible by jet veto ($E_T \geq 20$ GeV)



↑ early observation possible, already with ~1 fb⁻¹

$$H_{SM} \rightarrow WW \rightarrow l\nu l\nu$$

| LHC 14 TeV and MRSA Structure Function | | | | | | S/B | min. Lumi |
|--|---------------------------------------|----------|----------|------------|-------|------|------------------------------|
| M_H | Expected event rate for 30 fb $^{-1}$ | | | | | | |
| [GeV] | Higgs | $\sum B$ | W^+W^- | $t\bar{t}$ | Wtb | | for 5 σ [fb $^{-1}$] |
| 120 | 93 | 478 | 380 | 35 | 63 | 0.19 | 42.0 |
| 130 | 207 | 761 | 582 | 61 | 118 | 0.27 | 13.3 |
| 140 | 545 | 1403 | 1029 | 113 | 262 | 0.39 | 3.5 |
| 150 | 614 | 1223 | 853 | 126 | 244 | 0.50 | 2.4 |
| 160 | 879 | 586 | 376 | 64 | 146 | 1.50 | 0.6 |
| 170 | 688 | 586 | 376 | 64 | 146 | 1.17 | 0.9 |
| 180 | 1003 | 2777 | 1962 | 559 | 256 | 0.36 | 2.1 |
| 200 | 680 | 2604 | 1707 | 655 | 242 | 0.26 | 4.2 |
| 225 | 467 | 2604 | 1707 | 655 | 242 | 0.18 | 8.9 |
| 250 | 322 | 2204 | 1353 | 714 | 137 | 0.15 | 16.2 |
| 300 | 120 | 796 | 421 | 342 | 33 | 0.15 | 41.0 |
| 400 | 167 | 796 | 421 | 342 | 33 | 0.21 | 21.0 |
| 500 | 96 | 796 | 421 | 342 | 33 | 0.12 | 65.0 |

Table 1: Expected event rates for different Higgs masses and backgrounds with adjusted lepton p_t cuts for an integrated luminosity of 30 fb $^{-1}$ using a PYTHIA simulation with MRSA [13]. The signal and background cross sections include NLO K-factors for the Higgs cross section, a K factor of 1.5 is used for the continuum production of W^+W^- pairs [6] and the $t\bar{t}$ rate is normalized to the NLO estimated cross section of 759 pb from [10]. For the Wtb we use a total cross section of $\sigma \times BR^2$ of 6 pb which does not include any K-faktor.

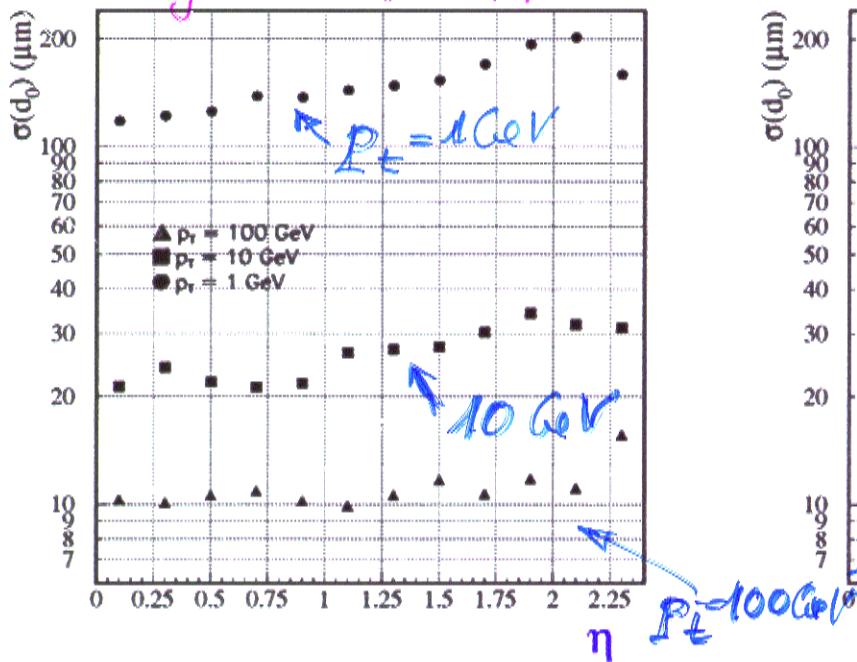
$H_{SM} \rightarrow bb$



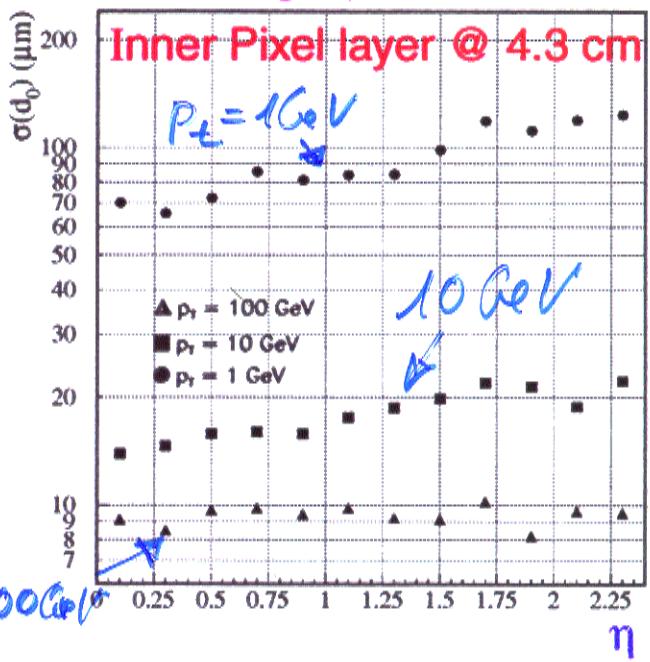
Impact Point Resolution

Transverse Impact Parameter

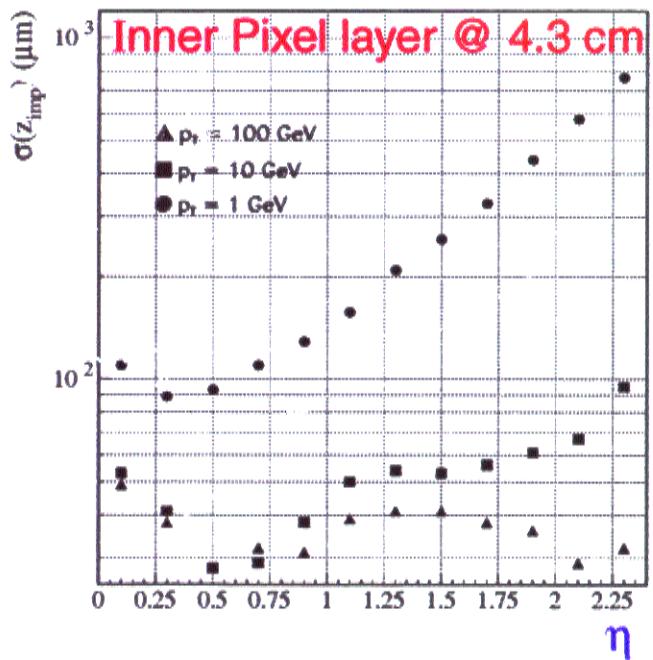
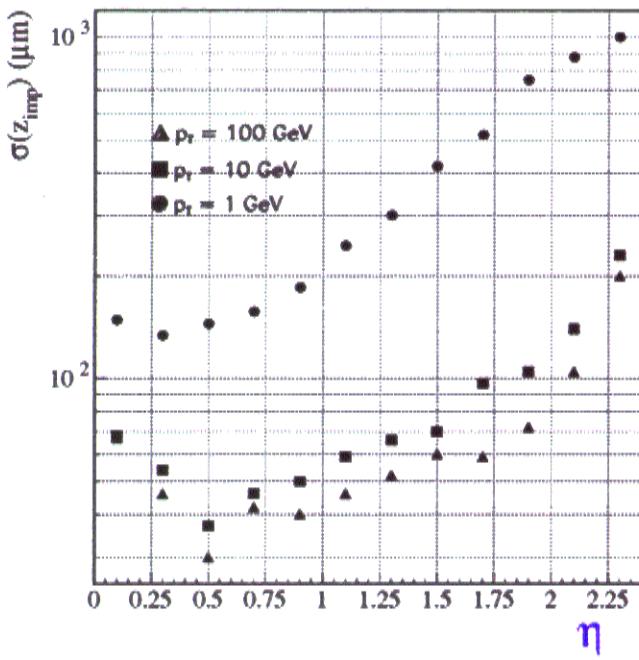
high \mathcal{L} tracker



low \mathcal{L} tracker

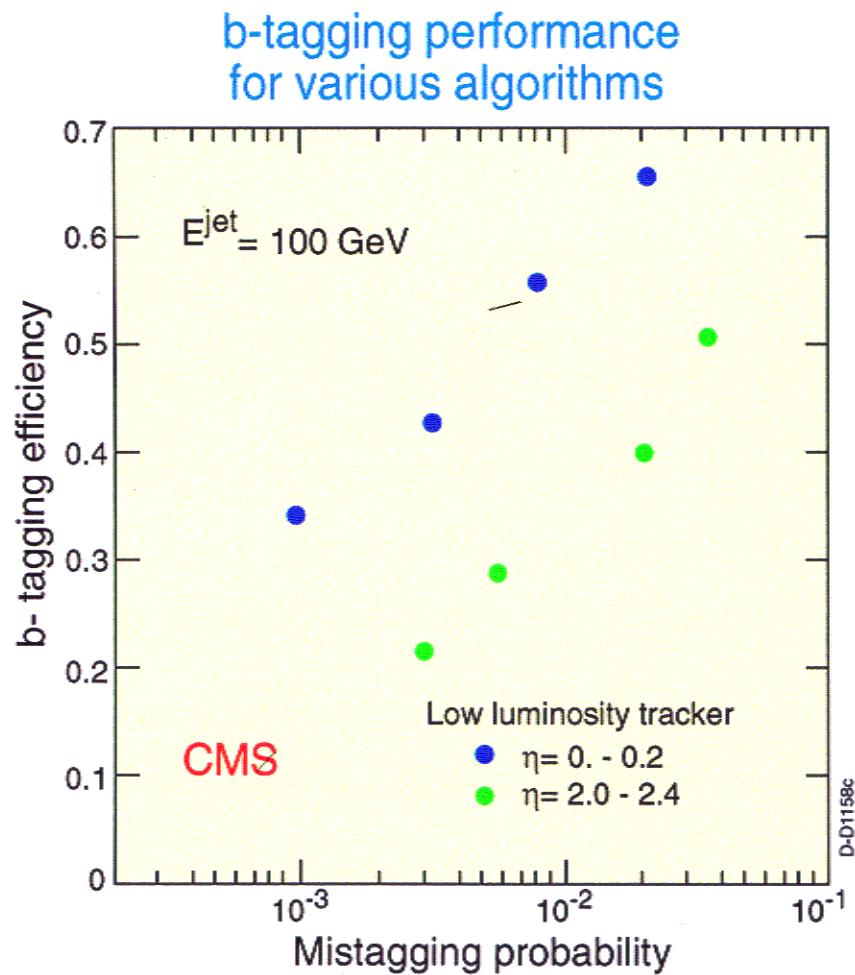
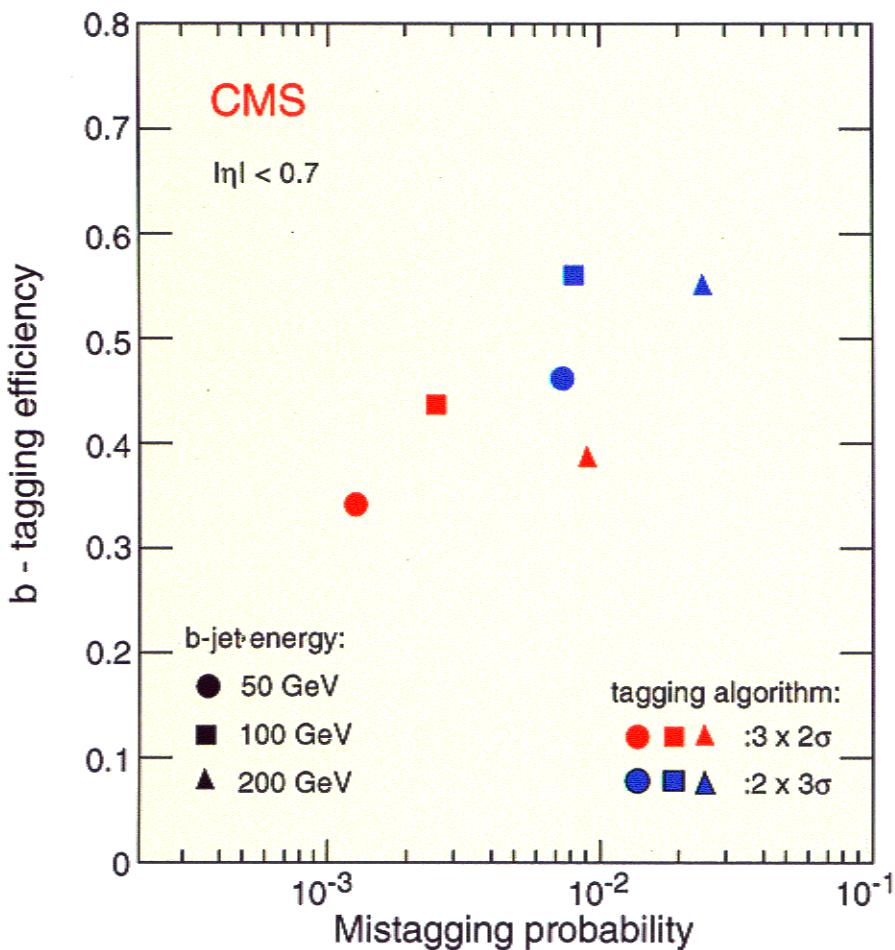


Impact Point z-coordinate



b - tagging performance of CMS

Low luminosity tracker full pattern recognition and track reconstruction

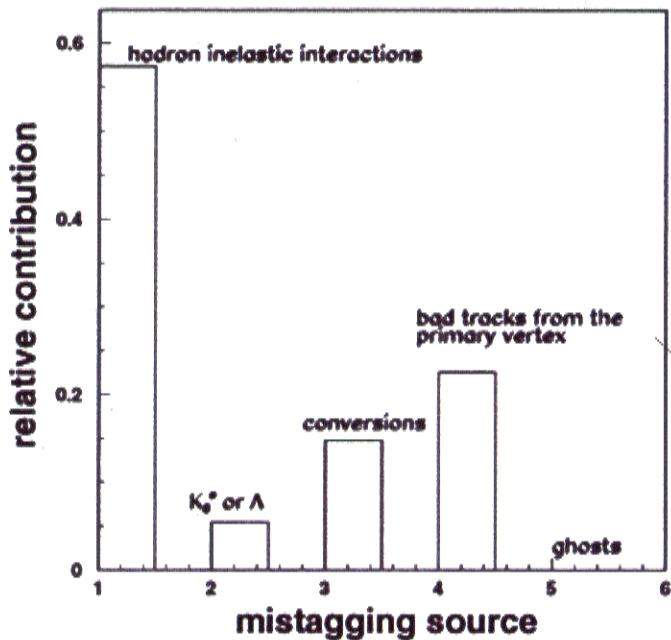


These are tagging efficiencies from impact parameter measurements, can be improved with lepton tags



Tagging b-Jets

analysis of fake tags

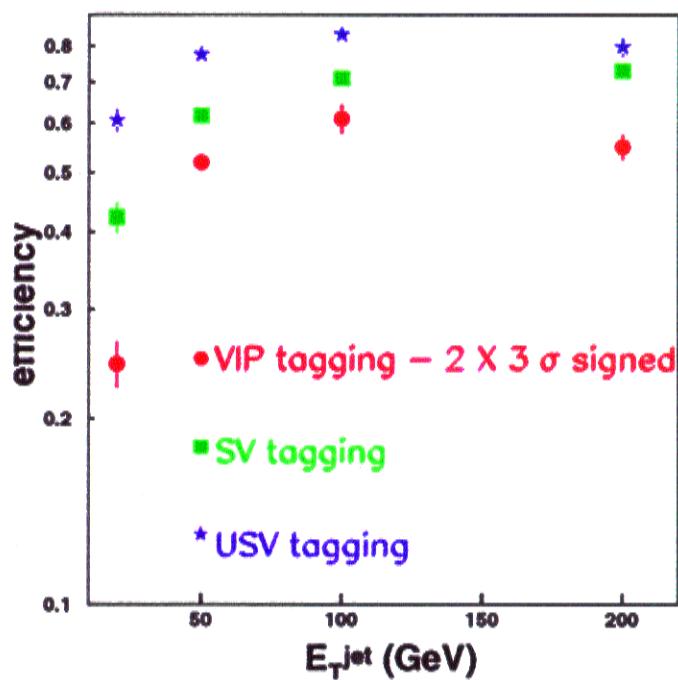
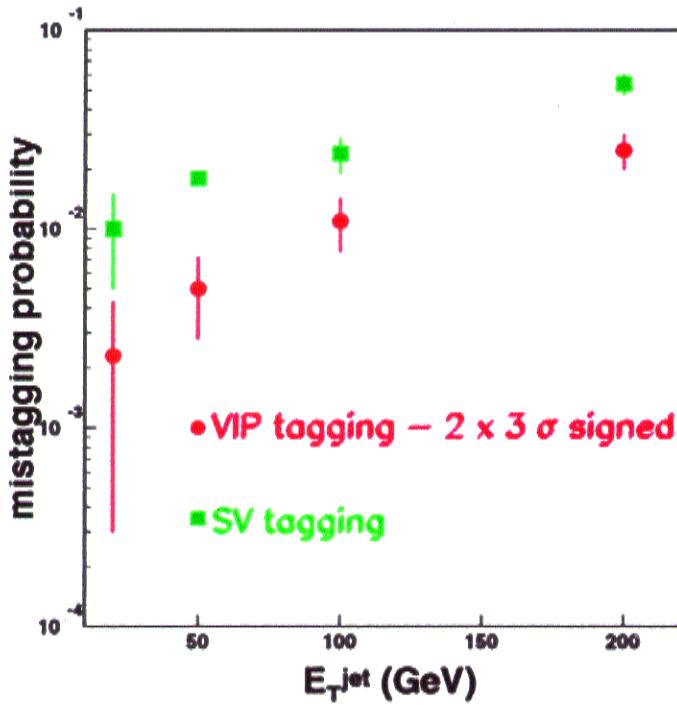


$E_T = 100 \text{ GeV jets}$

eff. = 62 %

mistag = 1.1 %

~ 78 % of the mistags is contributed by 'instrumental' background

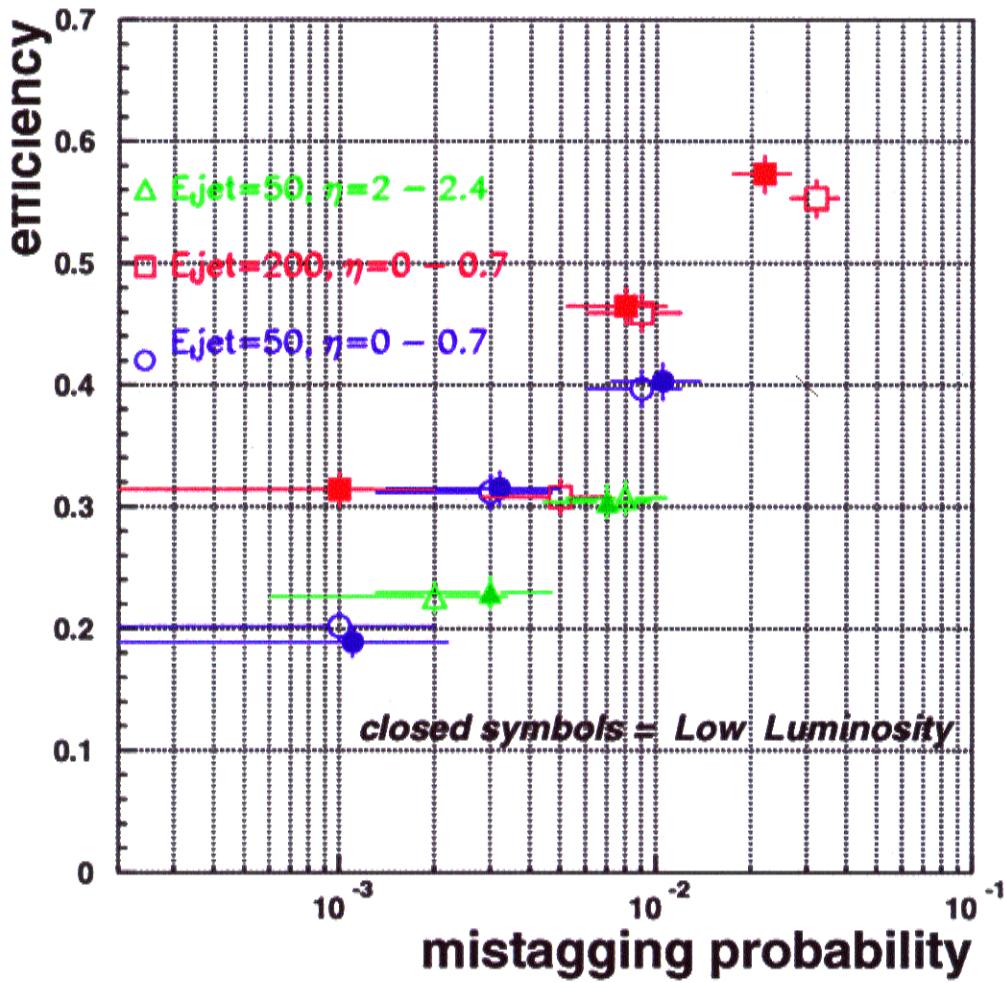


High b-tagging efficiency achievable with mistag-rate of a ~1%.



Tagging b -jets

Comparison Low vs. High Luminosity



Tracks are reconstructed with backward propagation algorithms and requiring at least 8 hits per track.

Tagging algorithms require N tracks with impact parameter significance S , $N, S = 2 - 3$.

The b -tagging efficiency and the mistagging rate observed at low and high luminosity are consistent.

Track reconstruction efficiency within jets

- various algorithms

CMSSW

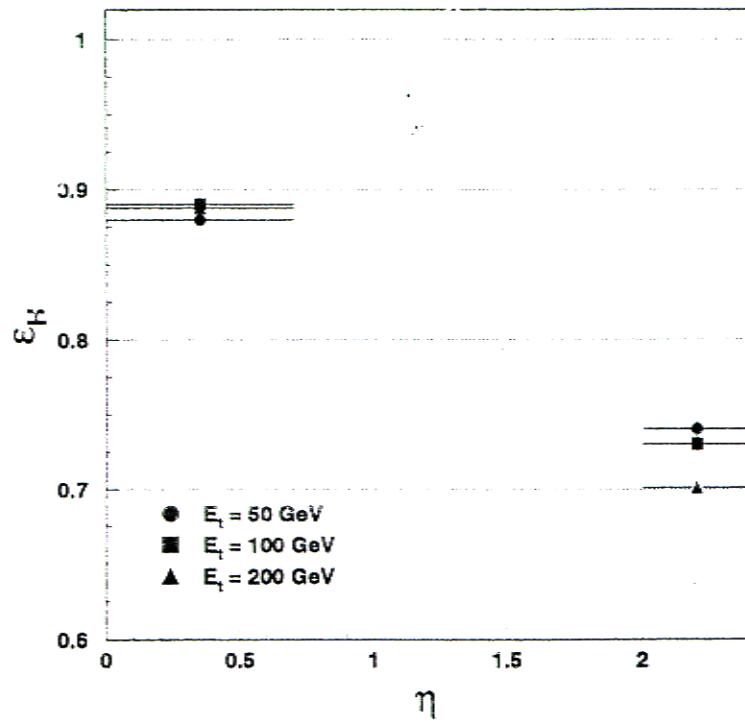
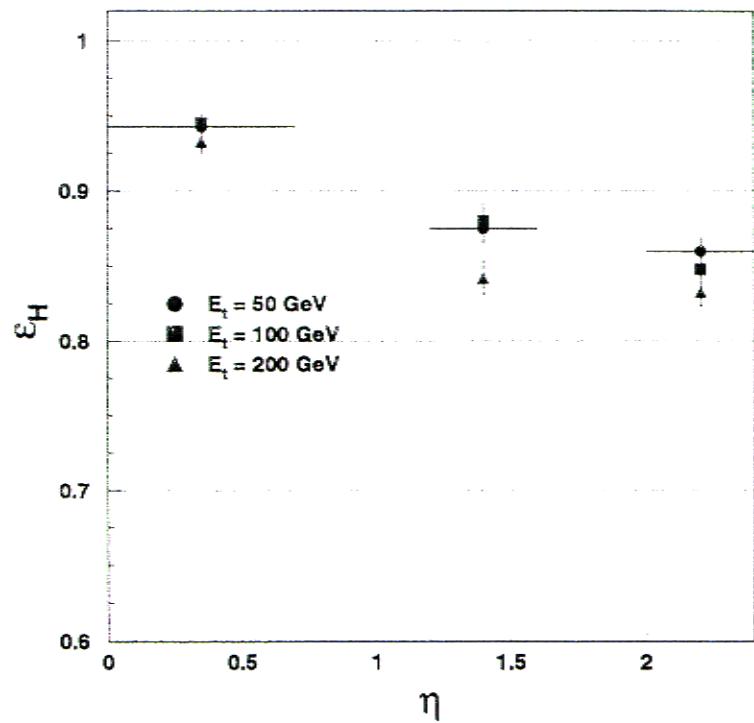
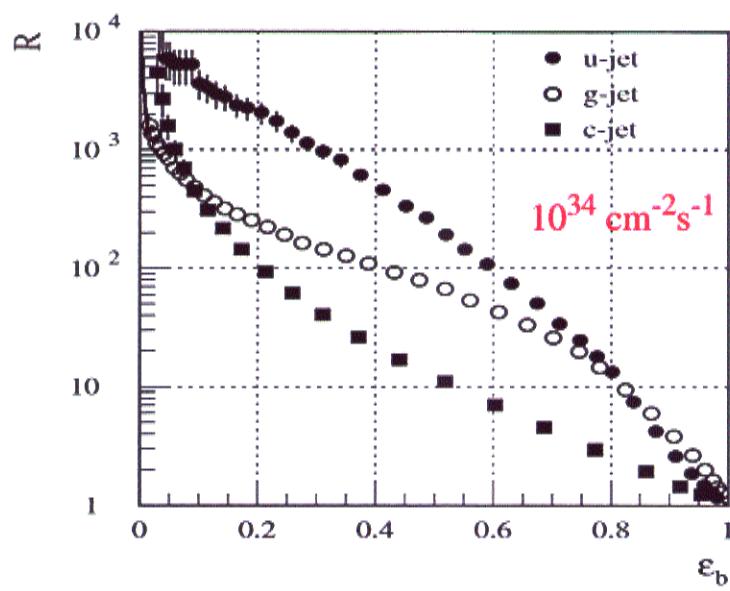
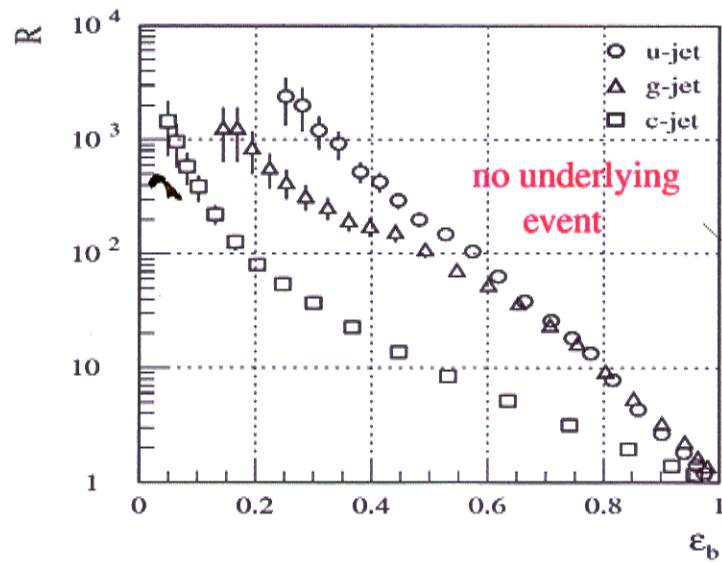


Fig. 9.39: Track reconstruction efficiency within jets as a function of jet pseudorapidity. Tracks are reconstructed with CM-FKF in the Phase I Tracker.

Fig. 9.40: Track reconstruction efficiency within jets as a function of jet pseudorapidity. Tracks are reconstructed with GTF in the Phase I Tracker.

B-tagging performance in ATLAS

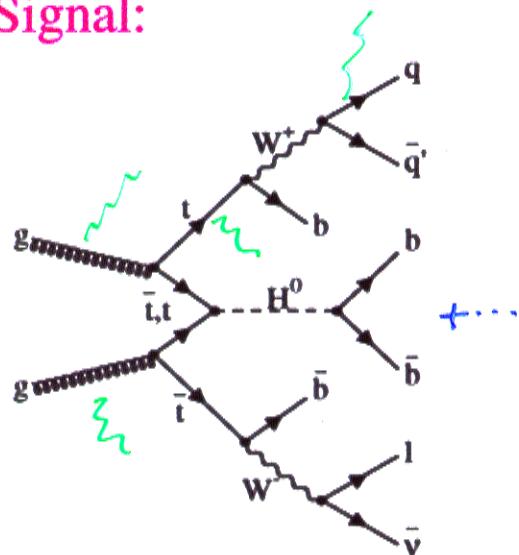
Rejection factor for u,g and c jets as a function efficiency for b jets
in $H \rightarrow b\bar{b}$ with $m_H = 100$ GeV



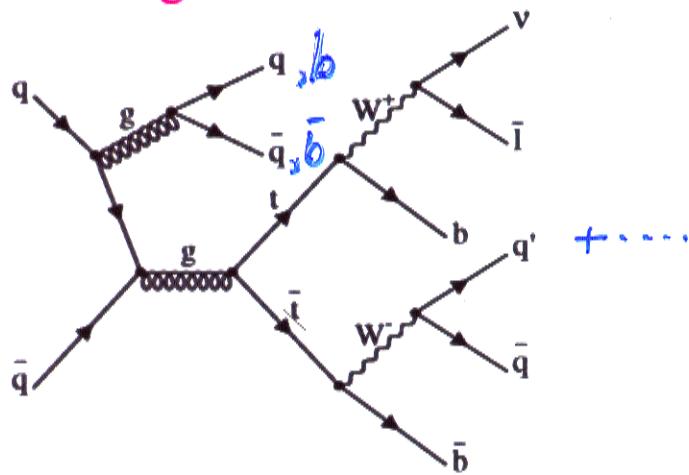
CMS - preliminary

$$t\bar{t}H^0 \rightarrow b\bar{b}$$

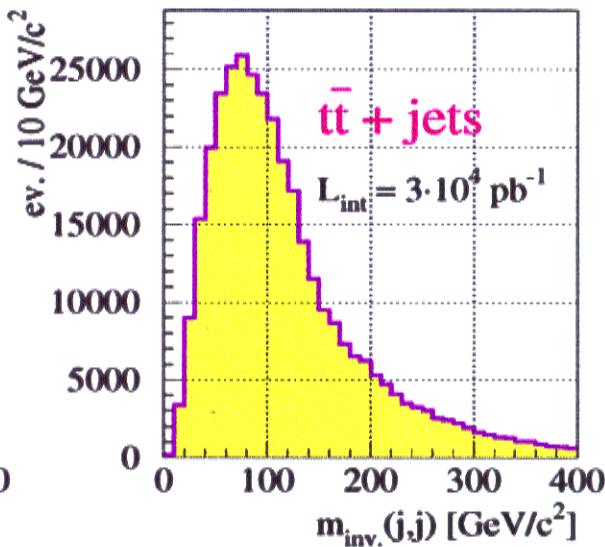
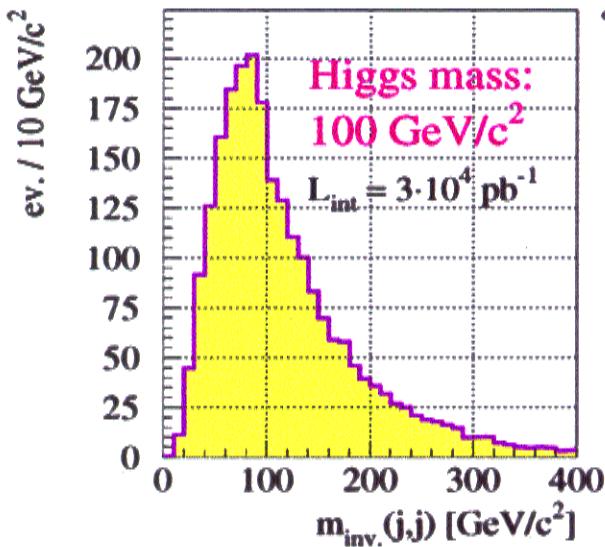
Signal:



Background:

**Event Reconstruction:**requirements: one isolated lepton $p_T > 20 \text{ GeV}/c$, at least six jets $|\eta^j| < 4.5$ at least three b -tagged jets with $0.6 < \Delta R_{j,j} < 2.8$

all possible combinations of invariant two jet masses are calculated



$t\bar{t}H, H \rightarrow b\bar{b}$ in CMS

preliminary results

Event selection for low luminosity ($L \sim 10^{33} \text{ cm}^{-2}\text{s}^{-1}$)

1 isolated lepton, $p_t > 10 \text{ GeV}$
at least 6 jets, $E_t > 10 \text{ GeV}$
4 tagged b-jets
reconstruction of m_W , $m_{\text{top}}(\text{hadronic})$, $m_{\text{top}}(\text{leptonic})$
calculation of event likelihood for all 6 jet combinations

B-tagging algorithm applied on the reconstructed jets in $t\bar{t}H$ and background events
Impact parameter errors from full track reconstruction parametrized as a function of p_t and η

Average tagging efficiency/jet:

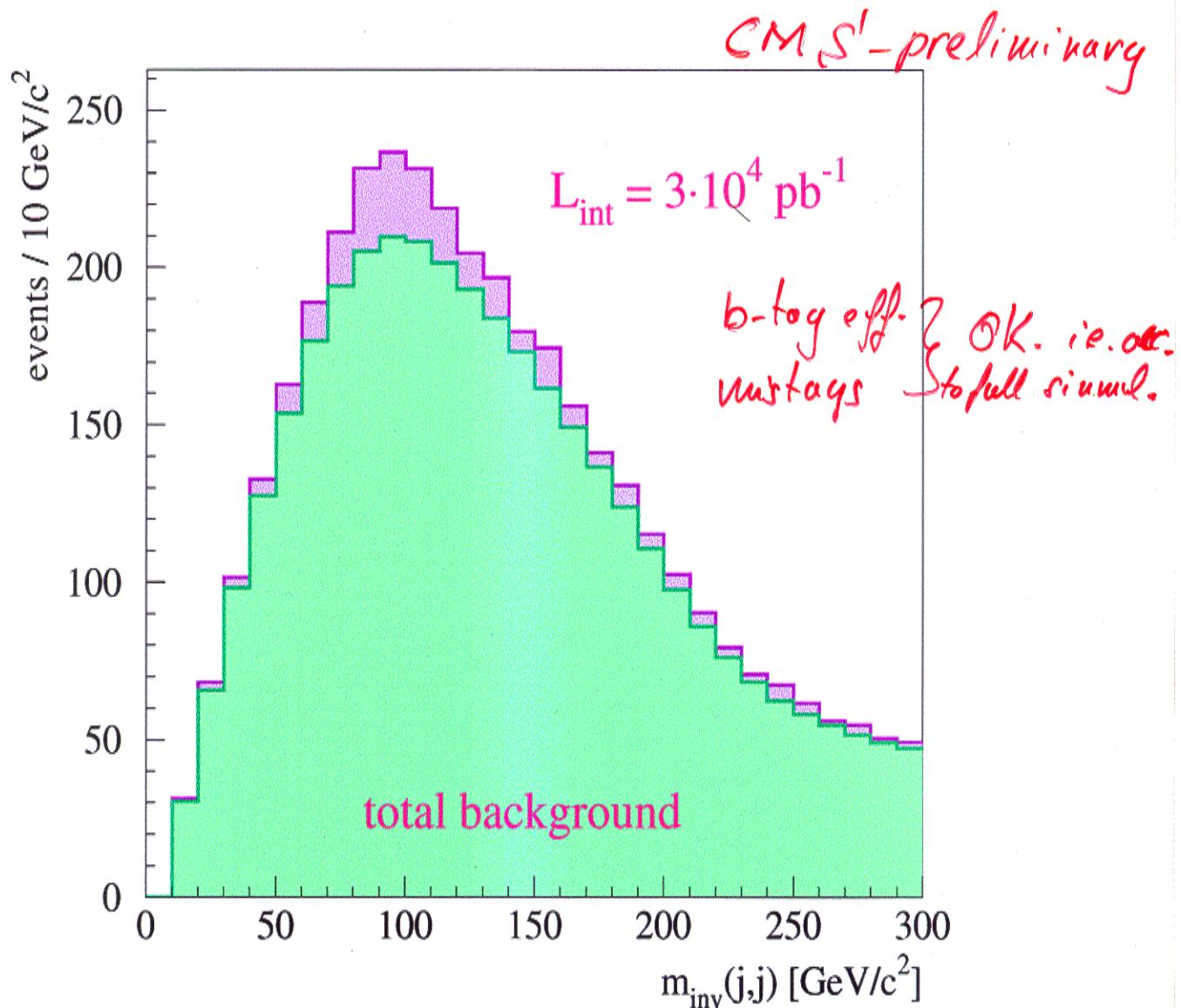
~ 50 % for b-jets
~ 2 % for light (q,g) jets

| m_H | signal eff. | S / B | S / \sqrt{E} |
|---------|-------------|-------|----------------|
| 100 GeV | 2.4 % | 0.12 | 3.0 |
| 120 GeV | 3.4 % | 0.06 | 1.9 |

$S + B$: 100 GeV Higgs

The Cuts:

- ◊ likelihood cut = 0.025
- ◊ $80 \text{ GeV} < m_{\text{inv}}(\text{j,j}) < 110 \text{ GeV}$



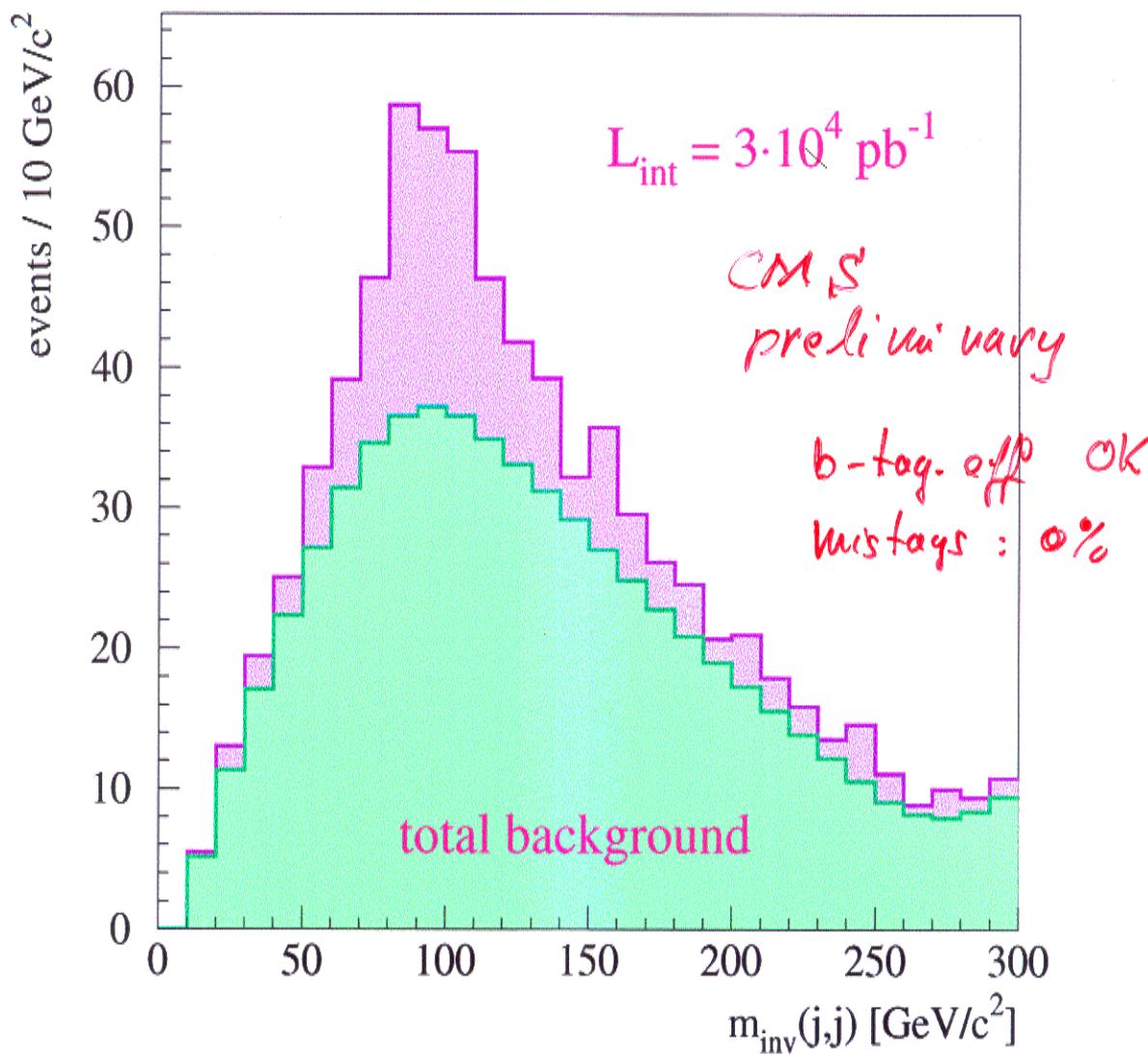
Results:

- ◊ signal rec. eff. = 2.4%
- ◊ $S/\sqrt{B} = 3.0$

$S + B$: 100 GeV Higgs

The Cuts:

- ◊ likelihood cut = 0.025
- ◊ $80 \text{ GeV} < m_{\text{inv}}(\text{j},\text{j}) < 110 \text{ GeV}$

**Results:**

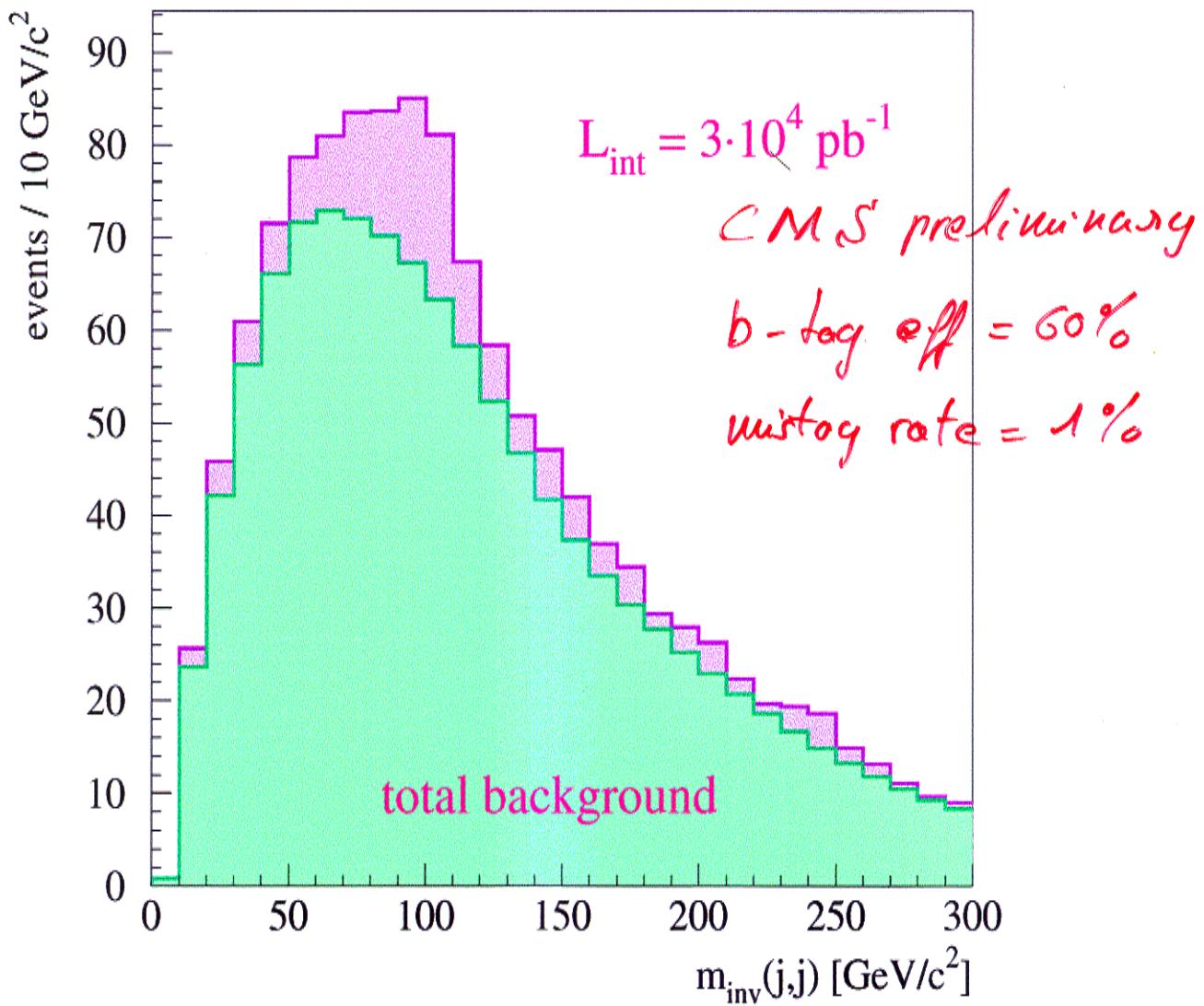
- ◊ 4 MC b -quarks
- ◊ $S/\sqrt{B} = 4.8$

$E_T^{\text{jet}} > 15 \text{ GeV}$

$S + B$: 100 GeV Higgs

The Cuts:

- ◊ likelihood cut = 0.035 $\rightarrow \approx 1.5\sigma$
- ◊ $75 \text{ GeV} < m_{\text{inv}}(\text{j,j}) < 110 \text{ GeV}$



Results:

- ◊ b -tagging: $\epsilon_b = 60\%$, $\epsilon_c = 10\%$, $\epsilon_q = 1\%$
- ◊ $S/\sqrt{B} = 3.8$

$$E_T^{e^+ e^-} \geq 15 \text{ GeV}$$

H \rightarrow b \bar{b} in t $\bar{t}H$ channel with full simulation

Irreducible backgrounds from t $\bar{t}b\bar{b}$, t $\bar{t}Z$

Reducible backgrounds t $\bar{t}jj$, Wjjjjj, WWbbjj,... with missidentified b jets

Event selection:

- One trigger lepton, $p_t^e > 20$ GeV (30 GeV), $p_t^\mu > 6$ GeV(20 GeV)
- At least 6 jets, $E_t > 15$ GeV (30 GeV)
- Exactly 4 tagged b-jets

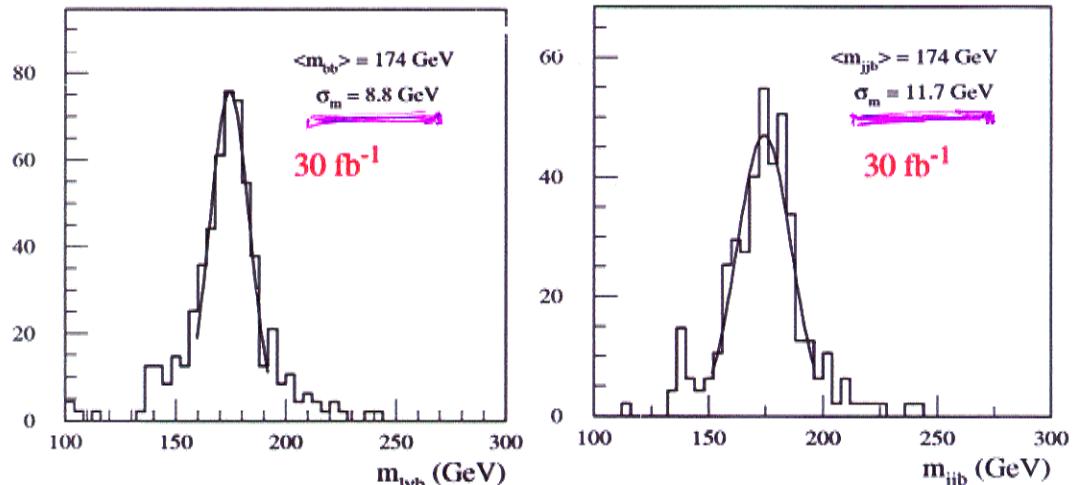
B tagging efficiency: 60% (50% for high luminosity)

mis rate: 1% for q, g jets, 10% for c-jets

Mass reconstruction with

W mass constraint for construction of v_L from $W \rightarrow l\nu$
and for rescaling of jet momenta in $W \rightarrow qq'$

Reduction of combinatorial background with minimization of
 $\chi^2 = (m_{jjb} - m_t)^2 + (m_{l\nu b} - m_t)^2$



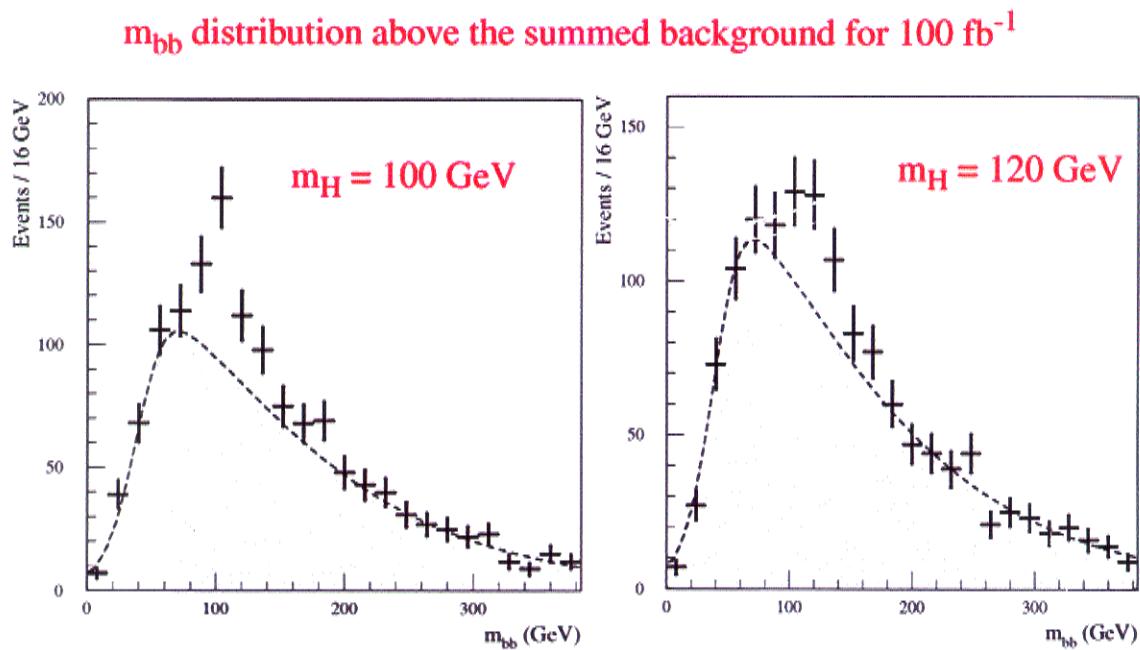
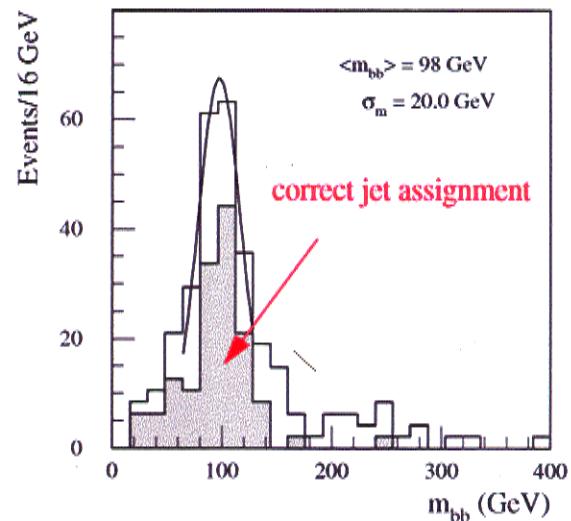
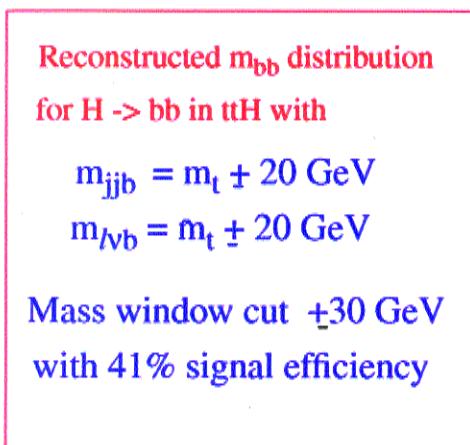
Reconstructed top mass from t $\rightarrow l\nu b$
in t $\bar{t}H$ with $m_H = 100$ GeV

Reconstructed top mass from t $\rightarrow jjb$
in t $\bar{t}H$ with $m_H = 100$ GeV

Efficiency of 66% for both top quarks in the mass window of ± 20 GeV

H \rightarrow b \bar{b} in t \bar{t} H with top reconstruction

ATLAS



30 fb^{-1} with low luminosity operation and 70 fb^{-1} with high luminosity operation

Total signal acceptance 1.7% at low lum., 0.7% at high lum.

$H_{SM} \rightarrow Z\gamma$

$H \rightarrow Z + \gamma$

CMS. first estimations for SM $H \rightarrow Z\gamma$, $Z \rightarrow \mu\mu/\text{ee}$ channel
 A. Nikitenko, Saclay/ITEP Moscow

| <u>M_H, GeV</u> | <u>140</u> | 150 | <u>160</u> | 170 |
|---|------------------|------------------|------------------|------------------|
| $\text{Br}(Z\gamma) \times 10^{3*}$ | 2.47 | 2.37 | 1.19 | 0.39 |
| $\sigma(\text{gg} \rightarrow H), \text{pb}^{**}$ | 25.4 | 22.6 | 20.2 | 18.2 |
| $\sigma(\text{qq} \rightarrow \text{qq}H), \text{pb}^{***}$ | 3.7 | 3.4 | 3.2 | 3.0 |
| Signal: $\sigma \times$ $\text{Br}(H \rightarrow \gamma\gamma) \times$ $\text{Br}(Z \rightarrow 2l) \times$ <u>$\times 10^5, \text{pb}$</u> | 488 | 420 | 190 | 56 |
| Bkg. $\text{qq} \rightarrow Z\gamma$, $\sigma \times \text{Br}(Z \rightarrow 2l)$ <u>$\times 10^5, \text{pb}^{****}$</u> | 30000 (51000) | 20000 (34000) | 14000 (24000) | 10000 (17000) |

After min. acceptance cuts: $p_t^\mu > 10 \text{ GeV}$, $|\eta^\mu| < 2.4$,
 $p_t^\gamma > 30 \text{ GeV}$, $p_t^e > 15 \text{ GeV}$, $|\eta^\gamma| < 2.5$, $1.46 < |\eta^e| < 1.59$
 and assuming $\varepsilon_{\text{rec}}^\mu = 0.9$, $\varepsilon_{\text{rec}}^{\gamma/e} = 0.8$:

| <u>expected number of events for $L=10^5 \text{ pb}^{-1}$</u> | | |
|--|-----------------------|----------------------|
| Signal: $2\mu/2e$ | 70/48 | 33/23 |
| Bkg. $\text{qq} \rightarrow Z\gamma$, $Z \rightarrow 2\mu/2e$ | 780/550 (1330/935) | 520/365 (880/620) |
| S/sqrt(B) | <u>3.2</u> (2.5) | 1.9 (1.5) |

* HDECAY

** NLO, CTEQ4M, $M_t = 175 \text{ GeV}$; from M.Spira HIGLU

*** LO, CTEQ4L ; NLO corrections are about 10 %

**** in $Z\gamma$ mass bin 2 GeV; PYTHIA 5.7 , CTEQ4M
 and for K factor 1 and 1.7 (in ())

H_{SM} → WW → lvjj

D.D93

Extension of the searches in the $H \rightarrow WW \rightarrow l\nu jj$ and $H \rightarrow ZZ \rightarrow llvv$ down to masses of 300 GeV

~ 30% of the production with $qq \rightarrow qqH$

Backgrounds from $t\bar{t}$, $W + \text{jets}$, WW

Central cuts for $H \rightarrow WW$:

lepton, $p_t > 50 \text{ GeV}$, $||\eta| < 2$
 $E_t^{\text{miss}} > 50 \text{ GeV}$, $p_t^{W \rightarrow l\nu} > 150 \text{ GeV}$
 2 jets, $E_t > 50 \text{ GeV}$, $p_t^{W \rightarrow jj} > 150 \text{ GeV}$
 $m_{jj} = m_W \pm 2\sigma$

Central cuts for $H \rightarrow ZZ$:

2 leptons, $p_t > 40 \text{ GeV}$, $||\eta| < 2.5$
 $E_t^{\text{miss}} > 150 \text{ GeV}$, $p_t^{Z \rightarrow ll} > 150 \text{ GeV}$
 $m_{ll} = m_Z \pm 6 \text{ GeV}$

Central jet veto:

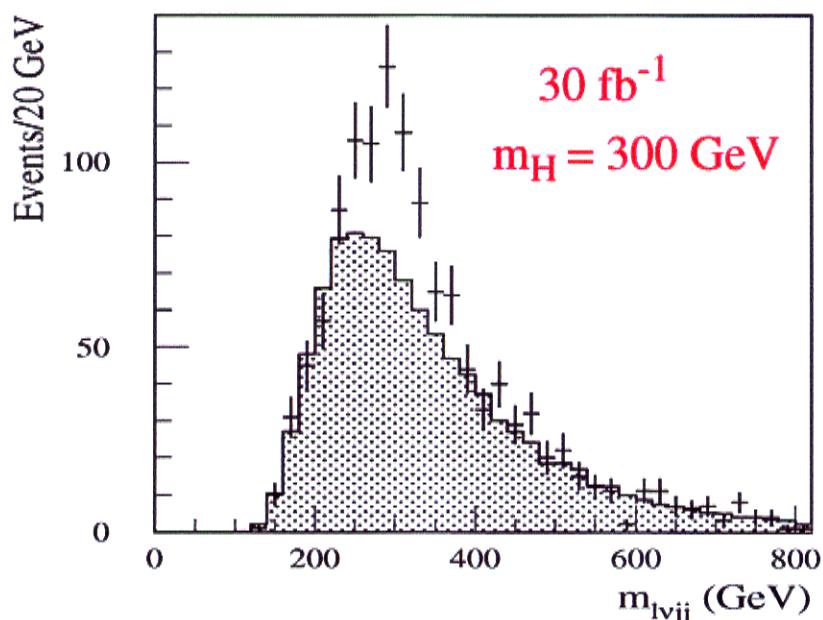
$E_t > 20 \text{ GeV}$

Signal acceptance 65%, rejection against $t\bar{t}$ ~14

Double jet tag :

$E_{\text{tag}} > 300 \text{ GeV}$, $||\eta| > 2$

Signal acceptance 51%, background rejection 30 to 300

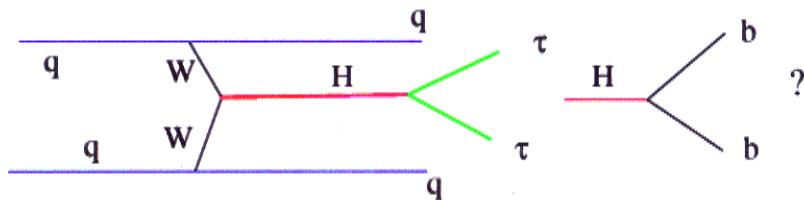


qq → qqH_{SM}

with H → ττ

$H_{SM} \rightarrow \tau\tau$ in qqH with $\tau_1 \rightarrow l\nu\nu$, $\tau_2 \rightarrow h+n\pi^0+\nu$

possibility to measure the $H\tau\tau$ coupling



Backgrounds from QCD Z+jj, EW Z+2j, Wj+jj, bbjj

Event selection:

- 1) Isolated lepton, $p_t > 15$ GeV
- 2) τ jet, $E_t > 30$ GeV
 τ identification in tracker and calorimetry with full simulation
 τ selection efficiency 30 %
 misidentification in W+jet events 1.9×10^{-3}
 b \bar{b} events $< 1 \times 10^{-3}$
- 3) Forward jet tagging: $E_t^{\text{jet}} > 30$ GeV, $\eta_{j1} * \eta_{j2} < 0$, $M_{jj} > 1$ TeV

| | $\sigma * \text{BR}$ | Events for 30 fb^{-1} with selection |
|----------------------|----------------------|---|
| $qqH, m_H = 135$ GeV | 0.17 pb | 7.4 |
| QCD Z+jj* | 3.94 pb | 1.2 |
| EW Z+2j** | 33.6 fb | 0.76 |

Colour structure in qqH disfavours jet emission in central region

→ further improvement of S/B possible with minijet veto

Cuts can still be optimized to improve statistics

* $p_t > 30$ GeV, $115 \text{ GeV} < m_{Z,\gamma^*} < 155 \text{ GeV}$

** $p_t > 20$ GeV, $m_{Z,\gamma} > 110$ GeV, $M_{jj} > 500$ GeV

At the time of Les Houches workshop

A. Nikitenko. contribution for Les Houches workshop



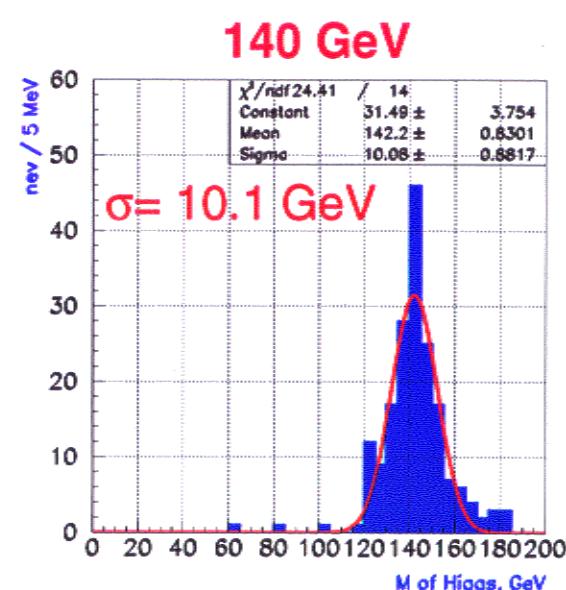
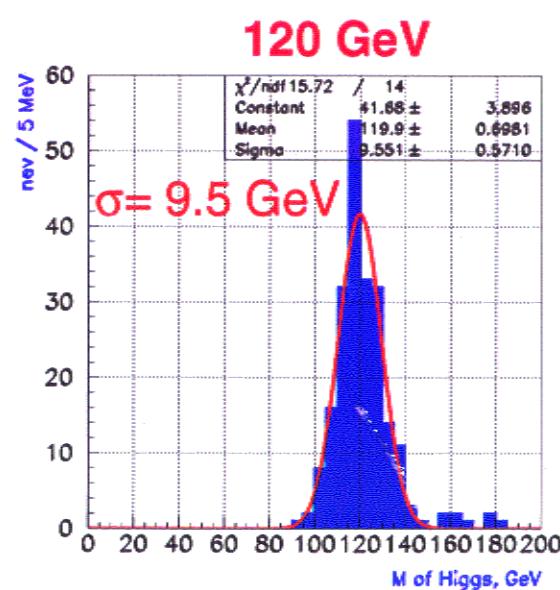
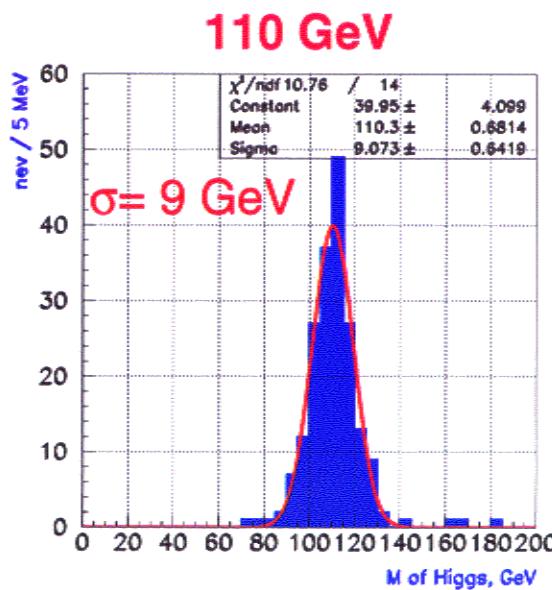
τ - jet identification obtained with full simulation of CMS calorimetry (R. Kinnunen, A. Nikitenko CMS Note 1997/002)

1. electromagnetic collimation: $\Sigma E_t^{\text{cryst}}(R < 0.13) / \Sigma E_t^{\text{cryst}}(R < 0.4) > r_{\text{cut}}$
2. calorimeter isolation : $\max E_t^{\text{ecal+hcacell}}(0.13 < R < 0.40) < E_t^{\text{cut}}$
3. one $p_t^{\text{hadr}} > 10 \text{ GeV}$, no tracks $p_t > 2 \text{ GeV}$ in cone 0.4

efficiency for τ -jet $E_t > 40 \text{ GeV}$ from Higgs of 140 GeV = 0.32

misidentification for jet from W+jet events = 0.0019; b-jet from bb events < 0.001

Higgs mass reconstruction assuming $m_{\tau}=0$





| | | Signal. M=135 GeV | QCD Z+j j* | EW Z+2j ** |
|----------------------------------|--|-------------------|--------------|--------------|
| | cross-section, pb | 3.81 | 117.3 | 1.0 |
| | $\text{Br } H \rightarrow \tau\tau ; Z \rightarrow \tau\tau$ | 0.045 | 0.0336 | 0.0336 |
| mc | $p_t^l > 15 \text{ GeV}, p_t^{\tau\text{-jet}} > 30 \text{ GeV}, \eta < 2.4$ | 0.275 | 0.169 | 0.61 |
| | lepton isolation in the tracker | 0.90 | 0.86 | 0.99 |
| | lepton isolation in the calorim. | 0.91 | 0.87 | 0.99 |
| | $\geq 3 \text{ jets of } E_t > 30 \text{ GeV}, \eta < 4.5$ | 0.51 | 0.24 | 0.72 |
| | tau-jet association (mc) | 0.92 | 0.85 | 0.99 |
| | $ \eta_j \text{ min} + 0.7 < \eta_l , \tau\text{-jet} < \eta_j \text{ max} - 0.7 , \eta_j \text{ min} - \eta_j \text{ max} < 0$ | 0.57 | 0.08 | 0.78 |
| | $ \eta_j \text{ max} - \eta_j \text{ min} > 4.4$ | 0.70 | 0.36 | 0.84 |
| fast detector simul. with cmsjet | $M_{jj} > 1 \text{ TeV}$ | 0.59 | 0.32 | 0.73 |
| | $m_t(l, p_t^{\text{miss}}) < 30 \text{ GeV}$ | 0.77 | 0.72 | 0.60 |
| | $0 < x_{\tau l} < 0.75, 0 < x_{\tau h} < 1.0$ | 0.63 | 0.60 | 0.77 |
| | $\cos\theta_{l\tau\text{-jet}} > -0.9$ | 0.99 | 1.0 | 0.85 |
| | $M_H \text{ window } 40 \text{ GeV}$ | 0.81 | 0.74 | 0.065 |
| | Number of events for 3 years at $L=10^{33} \text{ cm}^{-2} \text{s}^{-1}$ | 7.4 | 1.2 | 0.76 |

* QCD Z+j - pythia5.7; cteq4l, $p_t > 30 \text{ GeV}$, $M_{\gamma\gamma/Z} = [115-155] \text{ GeV}$;

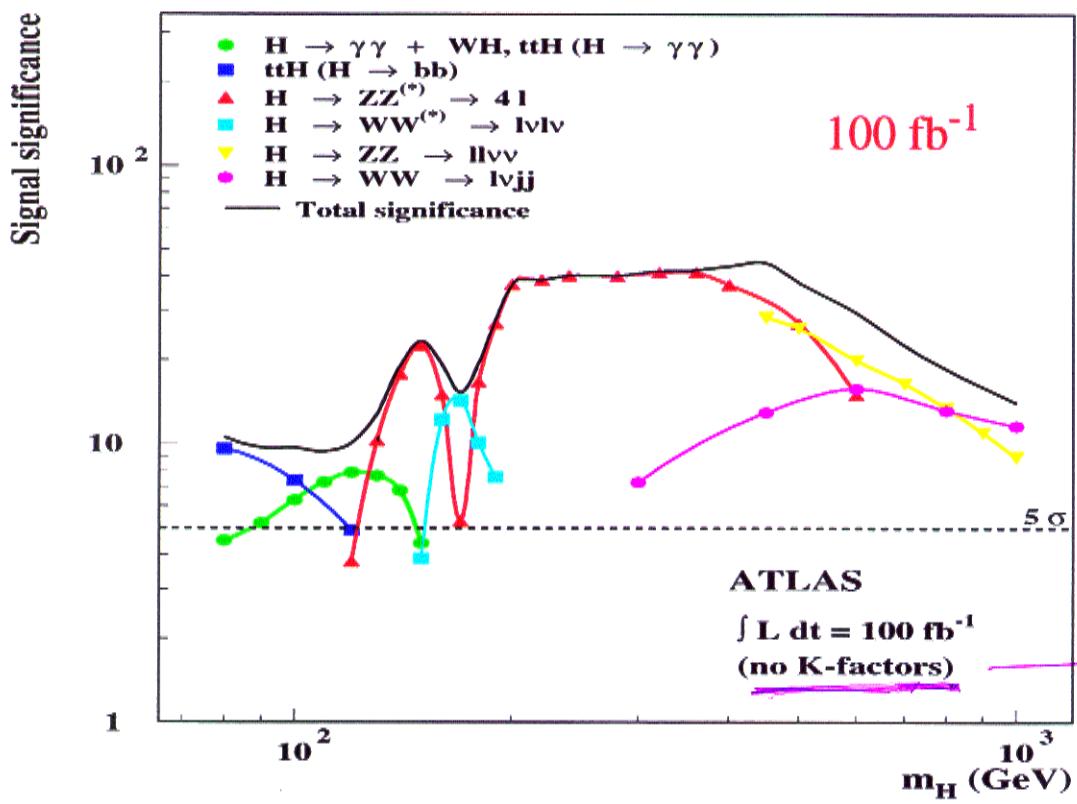
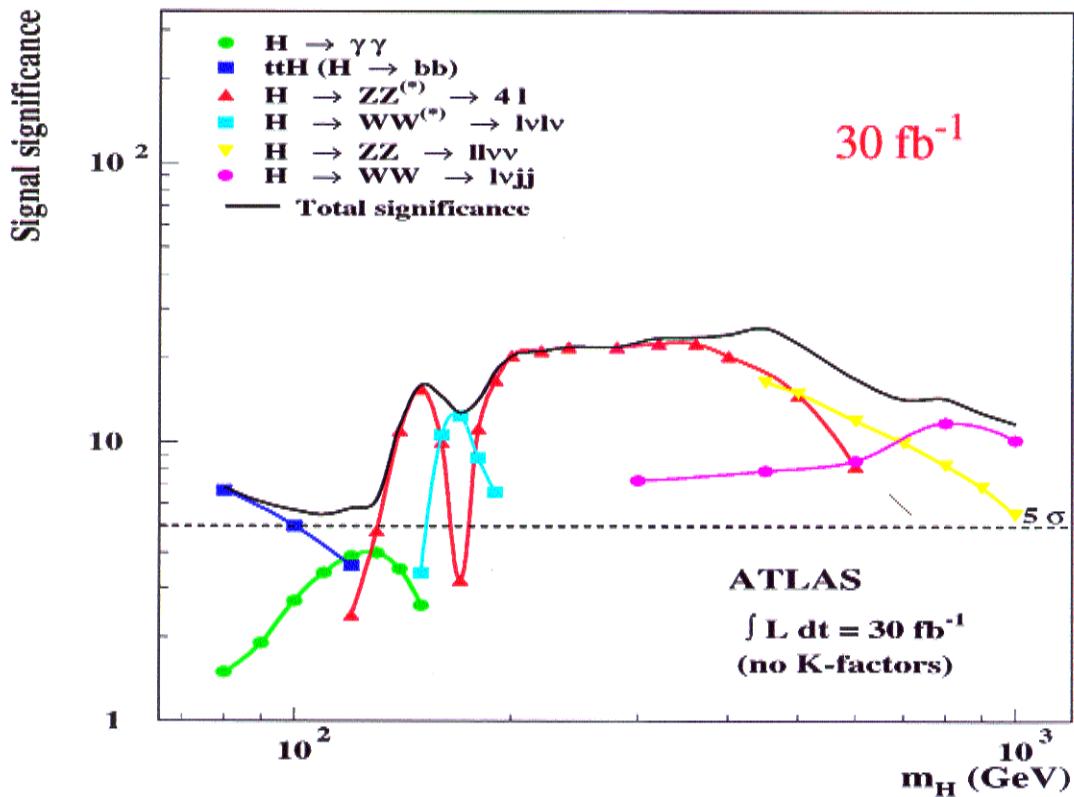
**EW Z+2j - gen. by S.Ilyin with comhep; cteq4m, $E_t^j > 20 \text{ GeV}$, $|\eta| < 5$, $M_Z > 110 \text{ GeV}$, $M_{jj} > 500 \text{ GeV}$, $Q = M_Z$; and passed into pythia5.7 ; no ISR and FSR is activated; undependent fragmentation

SM Higgs

mass coverage signal significance

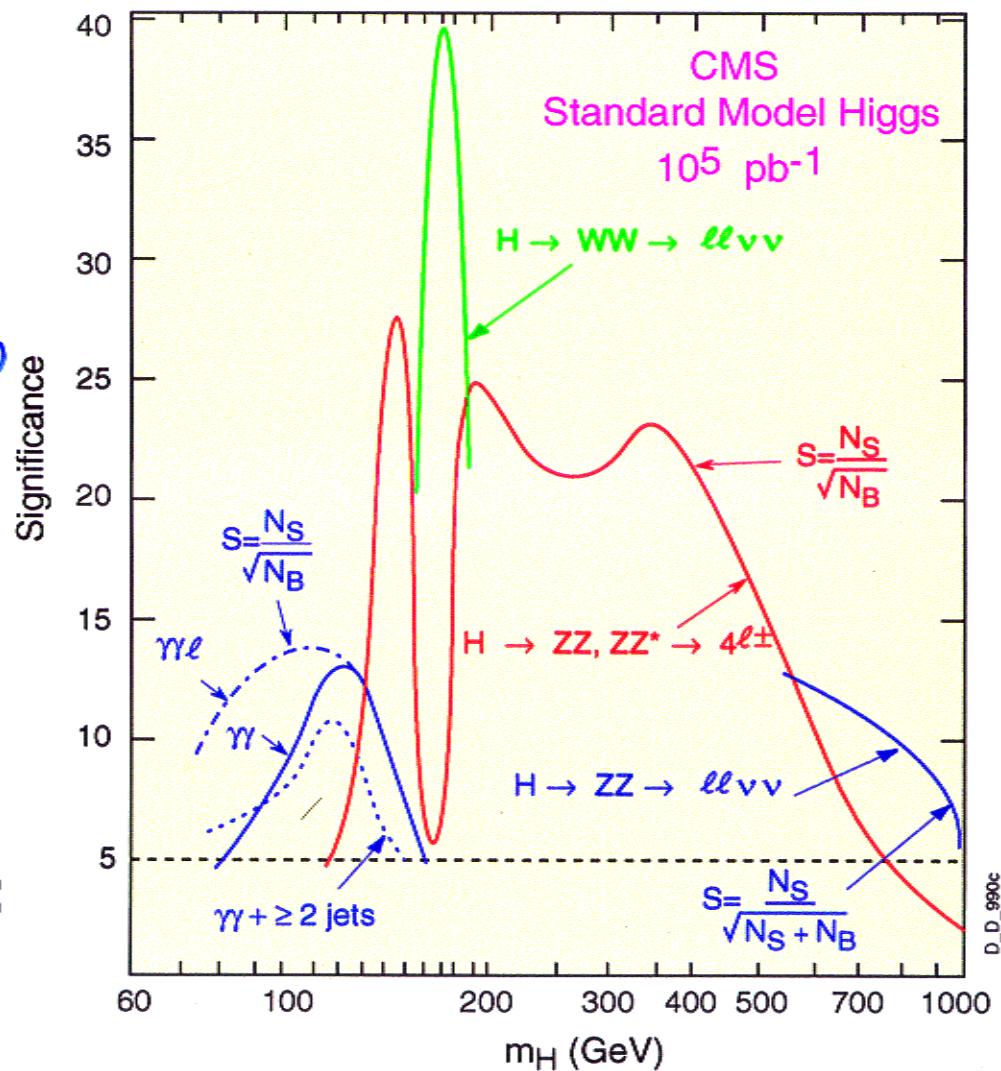
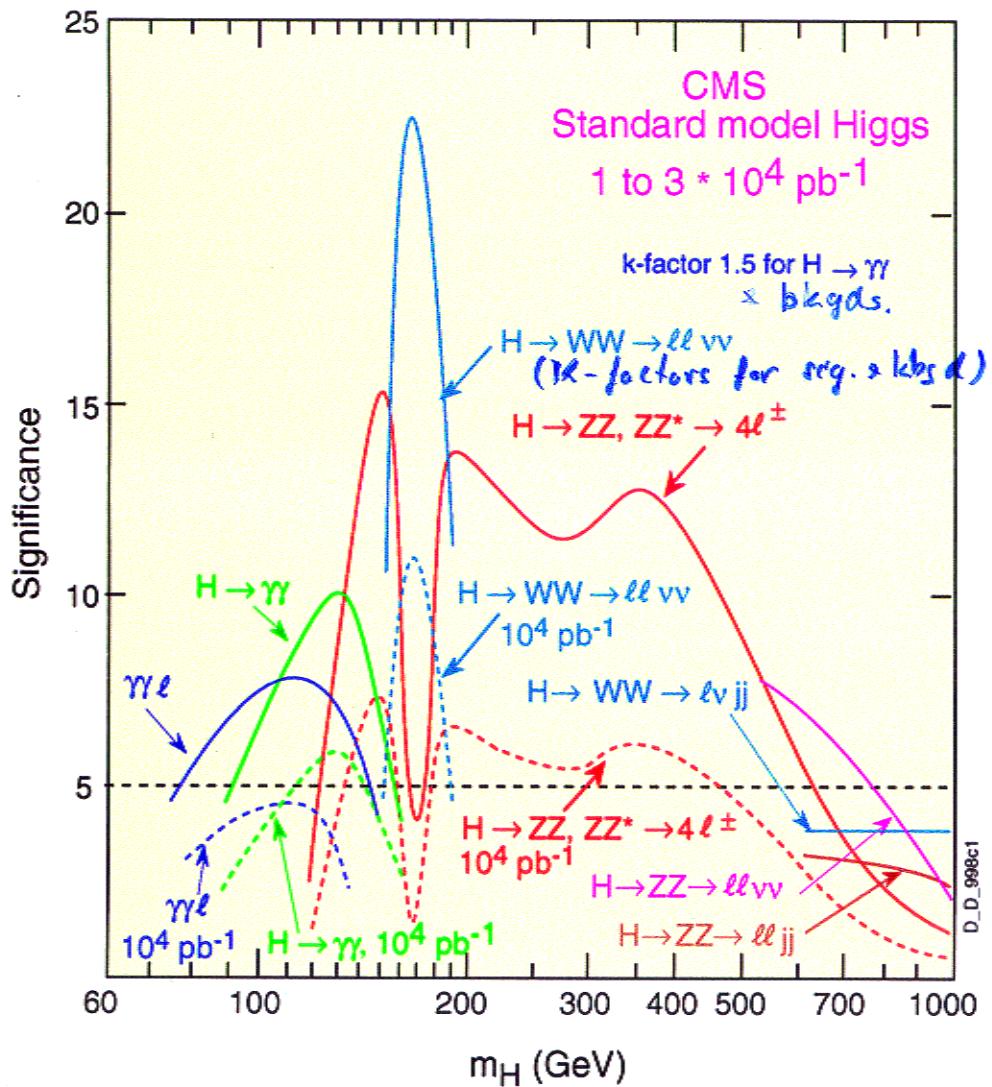
D.D. 99

Discovery reach for SM Higgs in ATLAS



conservative
view of
Higgs
as K-factors
for signals
K-factors for
likel.

Expected observability of Standard Model Higgs in CMS

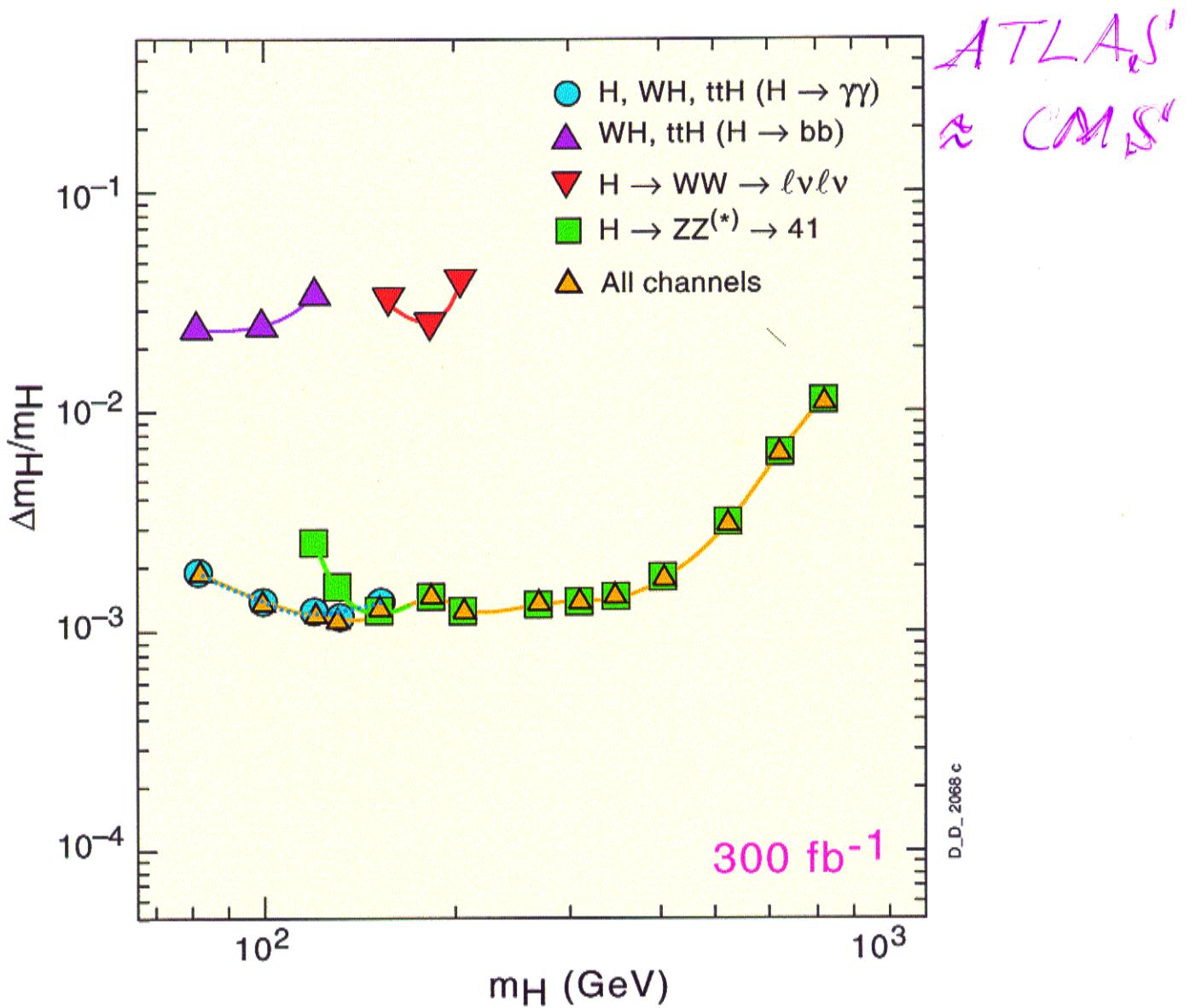


cuts not optimized in ZZ channel!

Precision on SM Higgs parameters

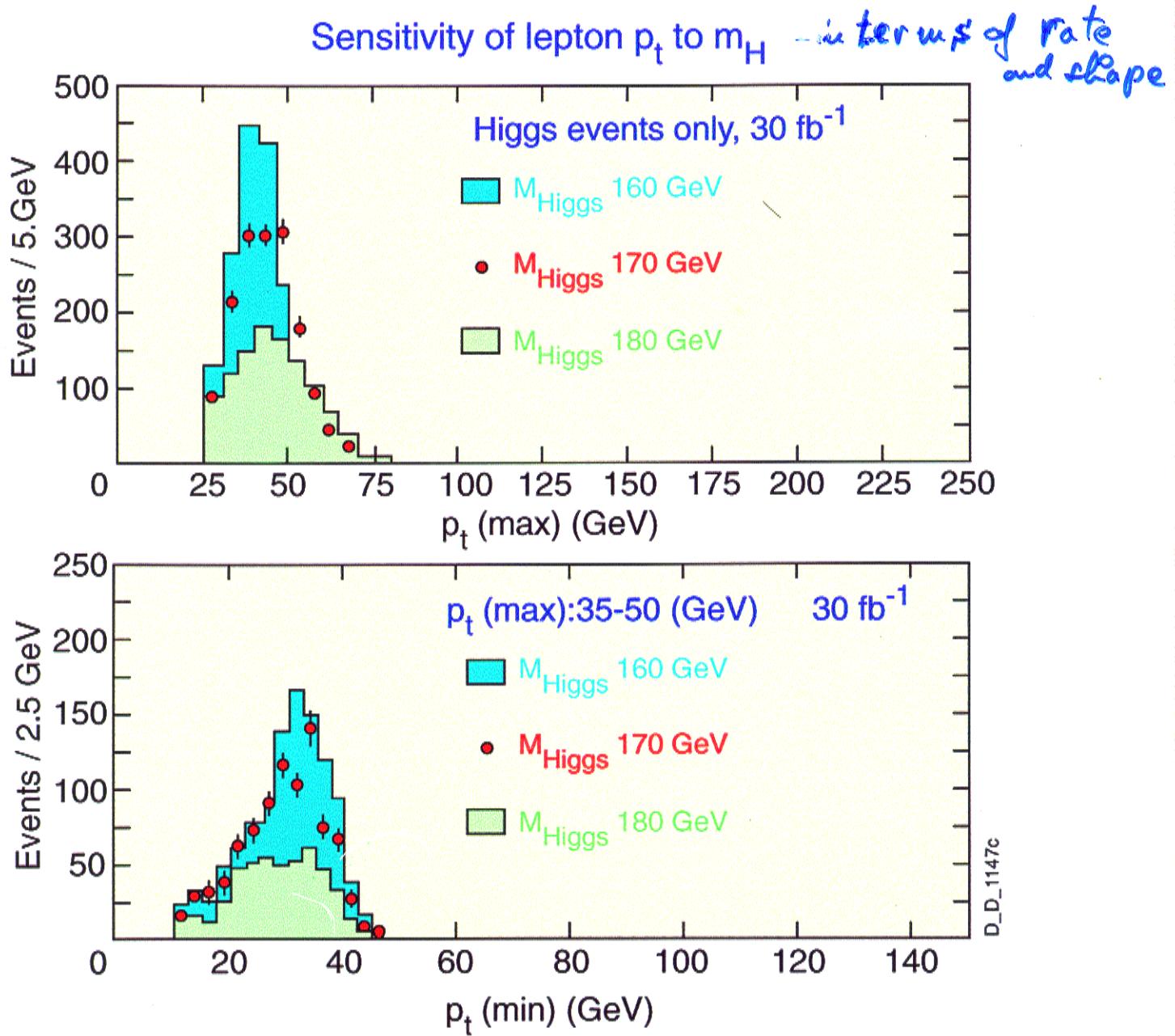
- mass
- width
- $\sigma^* \text{BR}$

Precision on SM Higgs mass



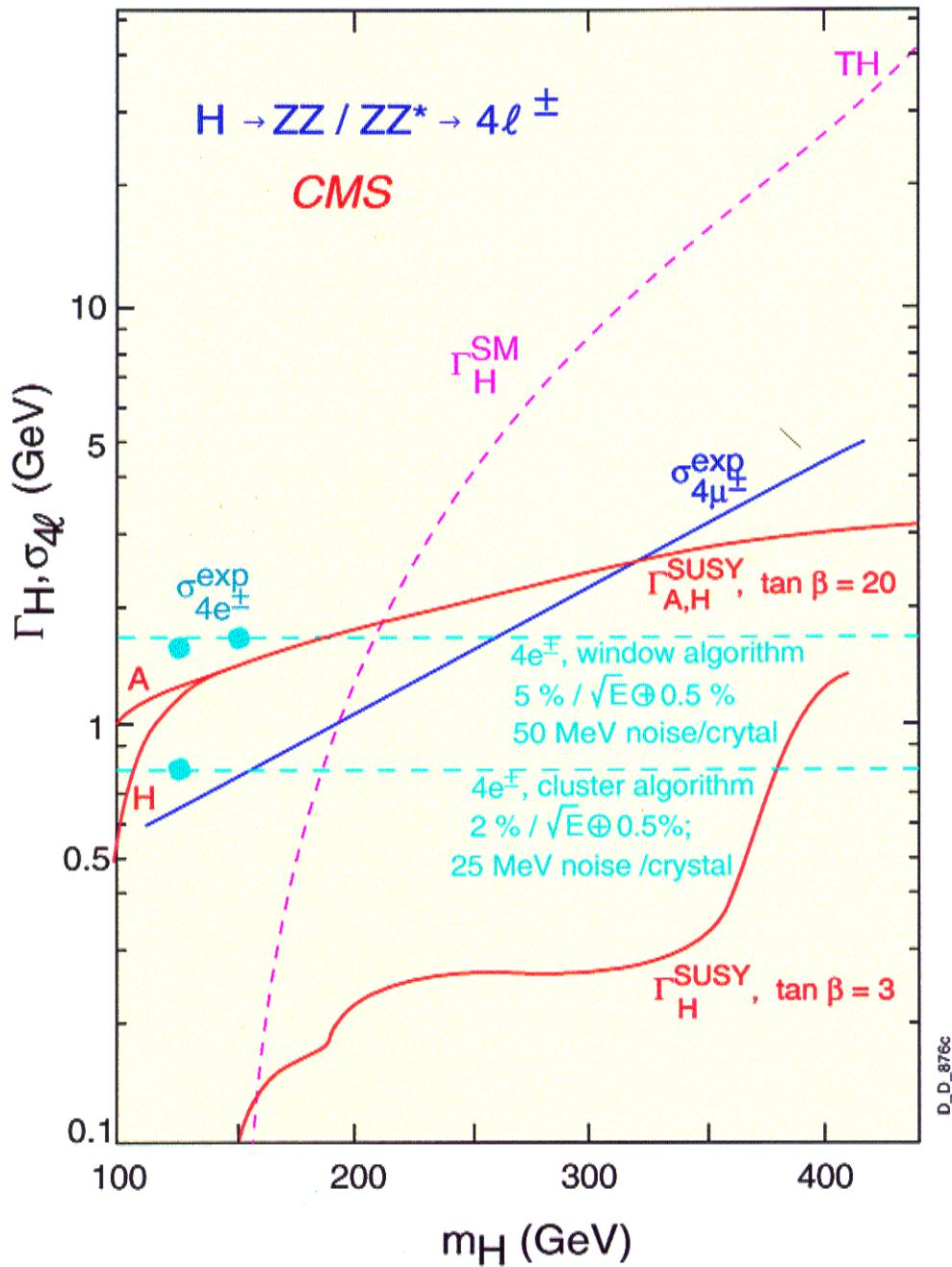
Limiting factor is knowledge of the absolute energy scale
for leptons and photons it is assumed to be known to 0.1% thanks to nearby Z
for jets it is assumed to be 1%

$H_{SM} \rightarrow WW \rightarrow \ell\nu \ell\nu$



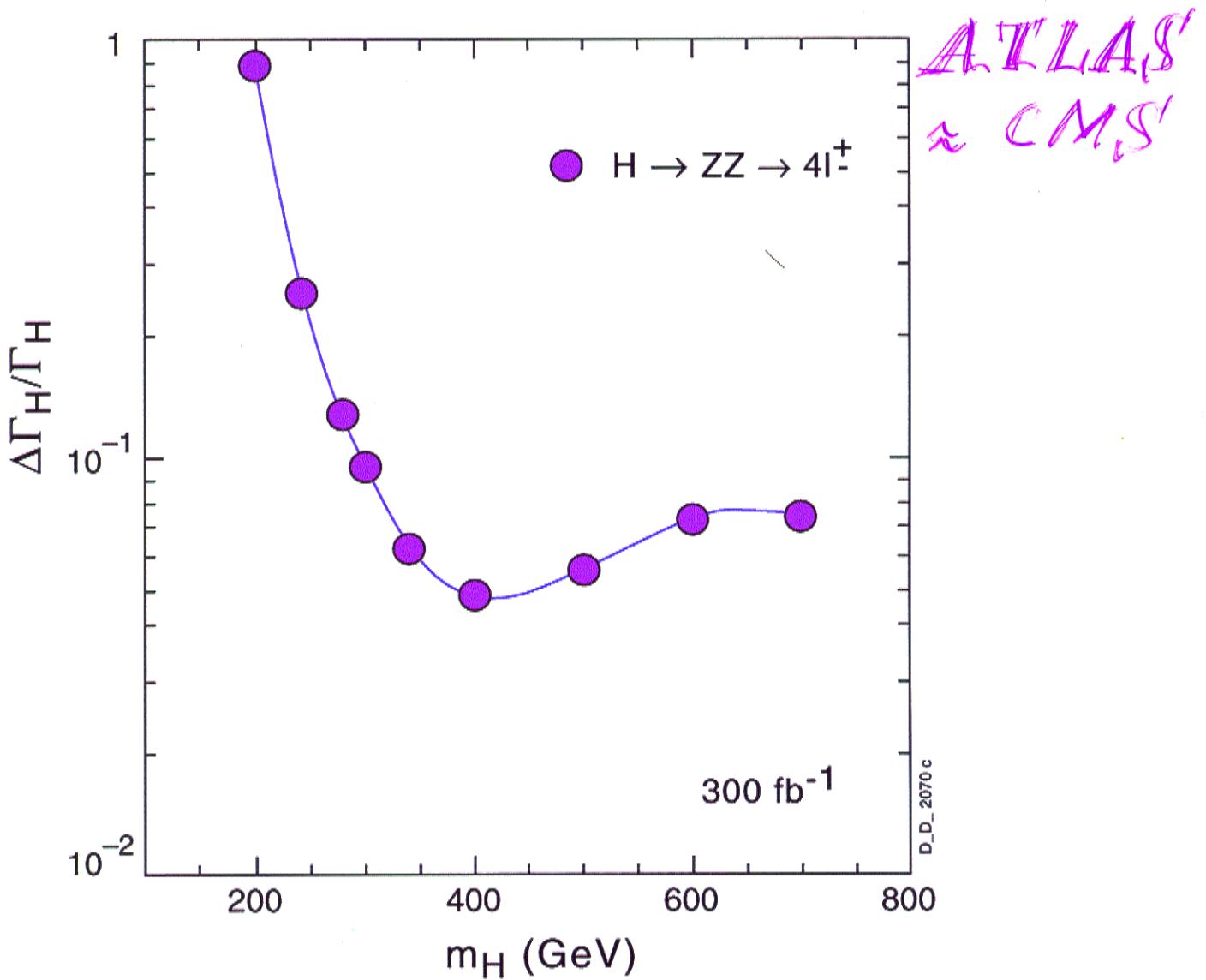
→ a precision on M_H of ~2-3 GeV could be achieved ultimately

Comparison of intrinsic Higgs widths with expected leptonic mass resolutions in CMS



- SM Higgs width is small (<1 GeV) up to $m_H \sim 200$ GeV
 - SUSY Higgs widths are small (< few GeV) for all masses and $\tan \beta$
- best possible 2 and 4-lepton mass resolutions to optimise S/B, ex. in $h, H \rightarrow 4l^{+-}$ or $h, H, A \rightarrow \mu\mu$

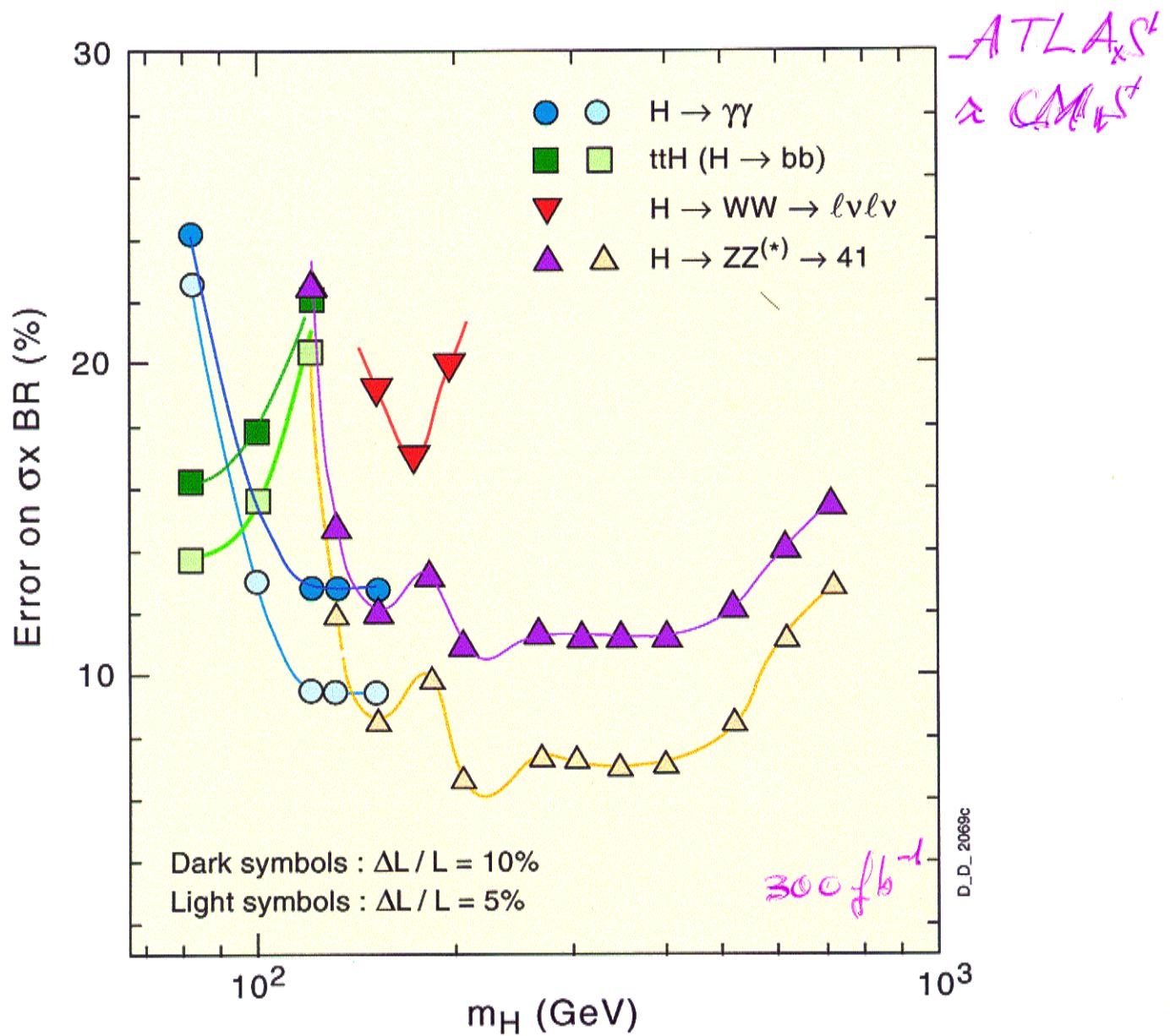
Precision on SM Higgs width



Limiting factor are radiative decays

systematic uncertainty assumed to be 1.5%

Precision on SM Higgs production rates



- Systematic uncertainty of 10% assumed on the background subtraction
- Luminosity assumed to be known to 10 to 5%

SM-Higgs, precisions on couplings, BR's

- assuming 300 fb^{-1}
- in ratios & luminosity uncertainty largely cancels

$$\frac{\sigma \cdot \mathcal{B}(W H \rightarrow \ell \bar{\nu})}{\sigma \cdot \mathcal{B}(W H \rightarrow b \bar{b})} \Rightarrow \frac{\mathcal{B}R(H \rightarrow \ell \bar{\nu})}{\mathcal{B}R(H \rightarrow b \bar{b})} \quad \begin{array}{l} \text{known to } \sim 30\% \\ \text{stat. limited} \end{array}$$

only for: $80 \leq M_H \leq 120 \text{ GeV}$

$$\frac{\sigma \cdot \mathcal{B}(H \rightarrow \ell \bar{\nu})}{\sigma \cdot \mathcal{B}(H \rightarrow Z Z^*)} \Rightarrow \frac{\mathcal{B}R(H \rightarrow \ell \bar{\nu})}{\mathcal{B}R(H \rightarrow Z Z^*)} \quad \begin{array}{l} \text{known to } \sim 15\% \\ \text{stat. limited} \end{array}$$

only for: $125 \leq M_H \leq 155 \text{ GeV}$

$$\frac{\sigma \cdot \mathcal{B}(t \bar{t} H \rightarrow W b \bar{b})}{\sigma \cdot \mathcal{B}(W H \rightarrow \ell \bar{\nu} W b \bar{b})} \Rightarrow \frac{g_{H t \bar{t}}^2}{g_{H W W}^2} \quad \begin{array}{l} \text{known to } \sim 25\% \\ \text{stat. limited} \end{array}$$

only for: $80 \leq M_H \leq 130 \text{ GeV}$

$$\frac{\sigma \cdot \mathcal{B}(H \rightarrow W W^{*})}{\sigma \cdot \mathcal{B}(H \rightarrow Z Z^*)} \Rightarrow \frac{g_{H W W}^2}{g_{H Z Z}^2} \quad \begin{array}{l} \text{known to } \sim 30\% \\ \text{stat. (Z Z*) limited} \end{array}$$

for $160 \leq M_H \leq 180 \text{ GeV}$